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Non-destructive inspection of aircraft landing gear during residual strength testing.

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Abstract

The different kinds of fatigue tests are necessary to continue the life of ageing aircraft. The features of landing gear tests of medium-range aircraft are discussed in this article. Firstly, the fatigue testing with cyclic loading by loads, which act during standard-type flight, was done. Then different residual strength tests with stepped static loading were carried out: axle beam torsion, braking during landing and running with landing weight. Acoustic emission (AE) and ultrasonic methods were used to check fatigue crack initiation and development. Then they were compared with the results of fracture analysis. High effectiveness of AE methods for the analysis of initiation and early development of fatigue failures in the process of cyclic loading and residual strength tests is shown.
Keyword: aircraft landing gear, fatigue cracks, acoustic emission.

To continue the operation of ageing aircraft which finished their specified service life it is necessary to carry out special strength and fatigue tests of main structure components. The following sequence of fatigue testing of the main elements is usually used:

- typical failures of the object structure are discovered during object operation;
- each from them is separately simulated (usually by strength concentrator inserting);
- the stand cyclic loading of an object is performed according to the program of operational load imitation; as a result, a fatigue crack of the given size grows from the concentrator;
- after that various residual strength tests imitating the limit operation states are carried out;
- the data obtained during these tests are used to redo and improve the design and structure of the object.

One of the most important features of such testing is to provide checking of a failure development by different non-destructive methods. In this case it is desirable to analyze the possibility of using these methods during further aircraft operation.

The features of a similar fatigue testing of the main landing gear leg of medium-range aircraft are discussed in this article. This leg consists of a shock absorber (including a cylinder and a piston with rod, which are joined by a hinge mechanism), a compensating actuator, axle beam assembly with wheels, rotation and retruction actuators, a lock mechanism, etc. The following typical failures occured during previous aircraft operation: disruptions of the shock absorber head, compensating actuator rod, hinge mechanism joints, etc. The strength of the lower element of the hinge mechanism was determined during the test.

For cyclic fatigue tests of this element the special strength concentrator – a notch with size 10.0x10.0x0.3 mm – was inserted into the lower hinge eye. This concentrator is critical during action of the maximum operational loads.

The loading program includes of the several blocks, each from which imitates the load changes during one standard-type flight. The typical standard flight consists of loads, which act during brake out, running, turnings before take-off, the take-off, landing and turnings after landing.

The main landing gear leg was loaded by three forces which were directed along the main coordinate axes of an aircraft. There are:

- $\mathbf{P_x}$ – force of forward impact;
- $\mathbf{P_y}$ – vertical force;
- $\mathbf{P_z}$ – side force.

Besides, the axle beam assembly turning was imitated by $\mathbf{M_y}$ moment. $\mathbf{P_y}$ and $\mathbf{P_{x0}}$ act upon the wheel axles; $\mathbf{P_{x3}}$ and $\mathbf{P_z}$ – upon the points of wheel/ground contacts; $\mathbf{M_y}$ moment was created by $\mathbf{P_z}$ load variation.

The variable and static loading was provided by several hydraulic cylinders which are controlled by the 24-channel automatic device AAN-01 through hydraulic/force transformers according to the given loading program. The loading program was supported by the "SERVOTEST" control system which is multi-channel closed-loop system with a feedback. The feedback signals were generated by different variants of linear variable differential transformers.

Periodical ultrasonic and uninterrupted acoustical emission (AE) checking was used for observation of a failure initiation and development. For this two ultrasonic and one AE sensors were installed to the lower hinge eye; additional sensors were used in the other leg components.

The fatigue testing was started from a cyclic loading. After 10000 cycles of loading by ultrasonic inspection the fatigue crack was discovered in the hinge eye. After landing gear disassembly the presence of the crack was confirmed by a visual checking and then by the method of magnet particles. The fatigue crack started from the concentrator.

Some of the AE data are represented in Fig.1. This is a change of cumulative AE $\boldsymbol{N_{AE}}$ versus the loading cycle number $\boldsymbol{N}$. It is possible to see that the graph has zones of fast and slow changes of $\boldsymbol{N_{AE}}$. Several zones are where the maximum changes of the AE parameter occur. There are 3 zones of maximum changes: zone 1, zone 2, and zone 3. It is usually possible to connect these changes with principal steps of a failure development. There is known a concept of staged development of a fatigue crack[1, 2]: for example, for 3-steged variant a microcrack transforms to a mezzo and then to a macrocrack. According to this concept, the zones marked in Fig.1, may be interpreted by a following way. There is a zone of microcrack appearance and its initial development (zone 1), a zone where the microcrack is transformed to a macrocrack (zone 2) and a zone of macrocrack development (zone 3). Therefore, the fatigue crack grows at different velocities: the periods of slow crack growth, where energy of destruction is accumulated in the interatomic links, are followed by the period of fast development, where the accumulated energy does its destructive work. Then, after the periods of a quick crack advancement, its development slows down because there is not enough energy to break off the interatomic links. This variant of explanation of the fatigue crack development was earlier used [3] for a cyclic loading of the object.

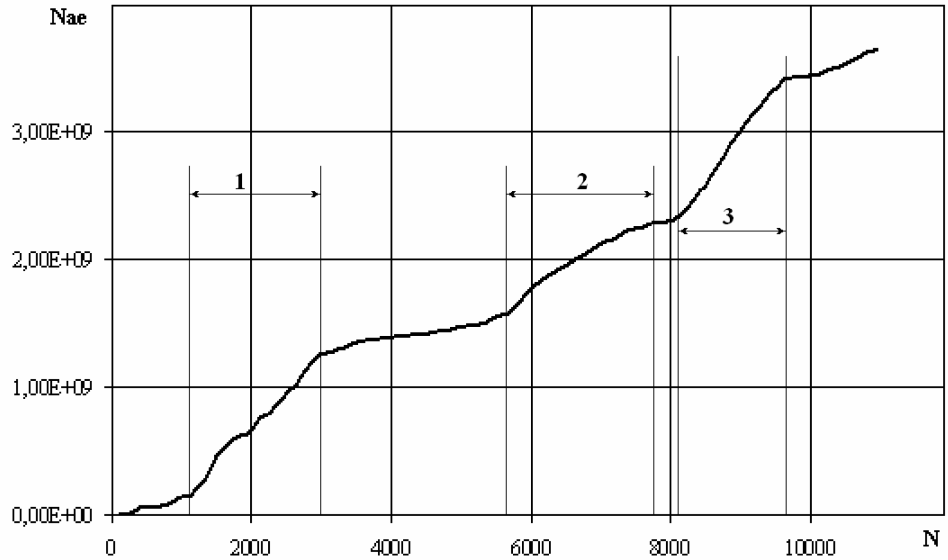

Fig. 1. **Cumulative AE N_{AE} versus loading cycle number N: 1, 2, 3 – zones of N_{AE} maximum changes**

The next step of the fatigue testing was a residual strength testing. Firstly, the variant "$\mathbf{M}_y$ – axle beam torsion" was implemented. This moment was created by $\mathbf{P}_y$ and $\mathbf{P}_z$ forces. The loads were increased step by step: in each step the load was increased by 10% of the maximum calculated breaking load and maintained during the given time (about 10 s).

The eye disruption happened when the load was equal to 52.7%. This disruption began from the fatigue crack which grew during the previous testing and developed in the inner cylindrical surface of the eye hole. However, the AE control shows (see, Fig.2a) that cumulative AE N_{AE} started increasing when the load was equal to approx. 40% of the maximum load. Most probably the fatigue crack begins to move at this moment in time.

As the landing gear leg did not lose its working capacity after the disruption of one eye, the next step of the fatigue test was implemented. It was the variant called "braking during landing". Similarly to the previous testing the static load was increased step by step. The maximum value of this load has reached 67% of the limit calculated breaking load. Visual and ultrasonic checking did not register any additional disruptions, but stress redistribution in the hinge was recognized by the tensile control. Checking by AE method does not show the principal changes of cumulative AE N_{AE} as well (see, Fig.2b): after some increase of the AE parameter in the range of 15...30% of the maximum breaking load, its growth slowed down. The analysis of the test showed a very small increase of $\mathbf{M}_y$. Probably it was the main cause of the absence of any additional failures in the landing gear structure.

For evaluation of the real residual strength of the landing gear leg an additional loading according to the "standard flight" program was carried out. The "standard flight" with an addition „turnings before take-off" loading after the main program was implemented. Visual and ultrasonic methods of non-destructive analysis were used after the testing, but no disruptions were registered.

However, the sharp growth of the cumulative AE was stated (see, Fig.3) during the loading program component „turnings before take-off". Probably it was the moment when a non-reversible disruption of the second cross-piece of the destroyed eye started. This conclusion is confirmed by the analysis of stress changes in the non-damaged eye of the lower hinge: the maximum $\mathbf{M}_y$ acted upon the eye this time.

The loading variant „running with landing weight" was a final step of a fatigue testing of the residual strength. Besides, the additional $\mathbf{M}_y$ is summed with the main load. The stepped loading was used as before. When the load was between 46.9% and 51.5% of the calculated-destroyed load the disruption of the second cross-piece of the lower hinge occurred. AE check showed that the disruption began when the load was equal to approx. 40% (see, Fig.2c).

After testing the destroyed elements of the lower hinge eye were investigated by a fracture analysis. As a result, the following conclusion were obtained:

- the fatigue crack began from the concentrator;

- the crack length equals 2.3 mm;
- the fatigue crack developed during approximately 9500 cycles;
- the crack development process was interrupted by 3 stop-overs (2900, 7750, and 9850 cycles approximately);
- disruption of the second eye occured without fatigue cracks.

These results confirm the main conclusion of AE checking. Actually, according to Fig.1, the moment of a crack initiation is located in the beginning of the zone 1 (1200 cycles approximately). Then, it is possible to observe a decrease of the cumulative AE N_{AE} growth at the ends of the marked zones: the end of zone 1 is approximately 3000 cycles; the end of the zone 2 – approximately 7700 cycles; the end of zone 3 – approximately 9800 cycles. Besides, according to the AE data it is possible to determine that the macrocrack began in the range of 8000...8500 cycles.

During the residual strength tests the AE data (Fig.2 and Fig.3) may be used for earlier information about disruptions. It is important, because it gives the opportunity to observe the failure development and prevent stand destroying during testing.

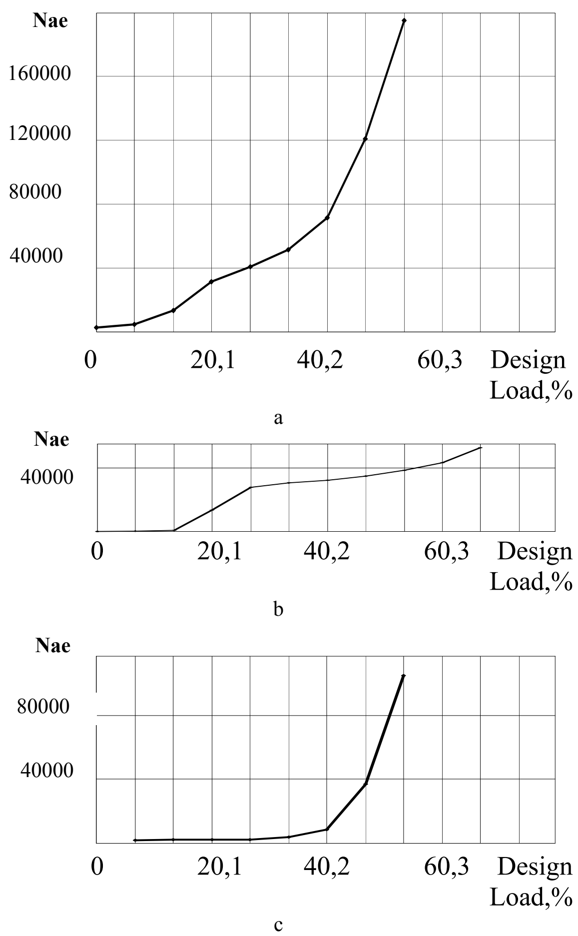

Fig. 2. **N_{AE} versus design load: a - during "M_y – axle beam torsion" loading program; b - "braking during landing" loading program; c - "standard flight" loading program**

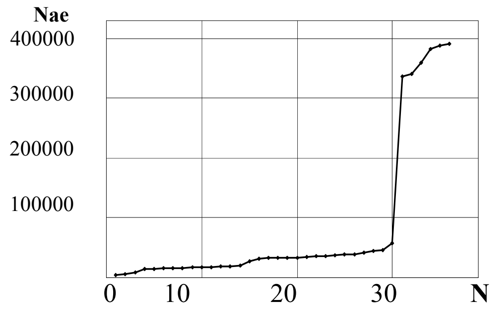

Fig.3. **N_{AE} versus N during„turnings before take-off" loading program.**

Thus, these results confirm high effectiveness of the AE method for the analysis of initiation and early development of fatigue failures during cyclic and residual strength tests.

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Lėktuvų leidimosi įrangos neardomieji bandymai liekamojo atsparumo tyrimuose

Reziumė

Norint pratęsti senstančių lėktuvų eksploataciją, reikia atlikti įvairiausių nuovargio tyrimų. Šiame straipsnyje nagrinėjami vidutinio nuotolio lėktuvų leidimosi įrangos tyrimo ypatumai. Pirmiausia buvo ištirtas ciklinių apkrovų, kurios veikia standartinių skrydžių metu, nuovargis, vėliau - liekamasis atsparumas esant skirtingoms statinėms apkrovoms – veleno skersinio sukimo, stabdymo leidimosi metu ir riedėjimo su leidimosi svoriu. Nuovargio trūkių atsiradimo ir didėjimo tyrimams buvo taikomi ultragarso ir akustinės spinduliuotės tyrimo metodai. Šių tyrimų rezultatai buvo palyginti su irimo mechanikos analizės rezultatais. Parodytas didelis akustinės spinduliuotės metodų efektyvumas juos taikant nuovargio trūkių atsiradimo ir pradinio didėjimo analizei, atliekant ciklinės apkrovos ir liekamojo atsparumo bandymus.

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