RIGA TECHNICAL UNIVERSITY

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USING ACOUSTIC EMISSION METHOD DURING BENCH-TESTS OF LOAD-BEARING AVIATION UNITS

Summary of the promotional work

Riga 2011

RIGA TECHNICAL UNIVERSITY
Faculty of Transport and Mechanical Engineering
Institute of Transport Technologies

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doctoral school program

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UDK 629.7.018.4:620.179.17(043.2)
Na 636 a

Nasibullins A. Using acoustic emission method during bench-tests of load-bearing aviation units Doctor diploma summary. R.:RTU, 2011.-30p.

Published according to the decision of the Promotion Council “RTU P-20” 01.06.2011., protocol № 01/2011

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

ISBN 978-9984-49-342-8

DOCTOR DIPLOMA
SUBMITTED TO RIGA TECHNICAL UNIVERSITY
TO OBTAIN ENGINEERING DOCTOR DEGREE

Doctor diploma to obtain engineering doctor degree has been openly presented on 25 august 2011 at 13:00 in the Institute of Transport Vehicle Technologies of Riga Technical University, Riga, Lomonosova street 1-V , room 218.

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CONFIRMATION

I confirm that this doctor diploma has been worked out and submitted to Riga Technical university to obtain engineering doctor degree. Doctor diploma is not submitted to any another university to obtain academic degree.

Aleksejs Nasibullins …………………………….

Data: ………………………

Doctor diploma is written in Latvian, it consists of preamble, 4 chapters, conclusions, list of literature, 5 appendixes, 70 drawings and pictures on 137 pages. The list of literature consists of 131 items.

Topicality of the work

At the present moment one of priority directions of the development of modern aviation is the increase of periods of aviation equipment safe operation. Conducting on-ground static and fatigue strength tests of aviation equipment and its components with the use of various methods of nondestructive testing (NT) is a necessary condition both for the certification of the new equipment and for the prolongation of the time of the operation of planes and helicopters already in use. As it is known, fatigue cracks in combination with metal corrosion are the principal causes of the formation of multi-center damages and the rise of catastrophic failures, which present the most danger in the process of the operation of aviation units. Therefore in the process of conducting fatigue tests it is important at the earliest stage to register the rise of fatigue failures and to control their development in the future.

Well worked-out and widely used NT methods, such as ultrasound, eddy-current, capillary, magnetic ones and others, have a number of shortcomings making difficult or impossible the use of those in a number of practical cases. Such shortcomings are, for example, the necessity of access to the surface under control, the influence of operational and technological factors upon the resolution of the methods, labor intensity of those. Most disadvantages inherent in the traditional methods of NT, may be overcome by way of using a perspective NT testing method – acoustic emission (AE) method.

The AE method allows to discover with great veracity structure defects and fatigue faults on hard-accessible sections of the unit and to keep a watch on the development of those during both fatigue testing and the operation. Using AE method, it is possible to discover defects at the early stage of the development as well as classify the damages by danger extent. However, it is rather difficult to use AE method in practice as energy level and principal characteristics of the useful signal depend significantly on properties of the material, and defect progress process is, as a rule, accompanied by noises having characteristics close to those of AE signal.

In this connection, the necessity of further perfecting the AE method, the establishment of criteria reflecting the extent of the damage to the structure of the material, the working-out and the introduction of procedures of early discovery of fatigue faults of load-bearing units conditions the **topicality** of the chosen subject of the investigation.

Purpose of the work

The purpose of the work is to show AE method efficiency when investigating regularities of fatigue fault accumulation process at the bench-testing of load-bearing aviation units. To work out a procedure of using AE method when conducting bench-tests of load-bearing aviation units. To work out an efficient AE criterion of the rise of fatigue cracks.

To achieve these objectives it is necessary to solve the following **tasks**:

1. To prove the correspondence of the first break on the diagram of the dependence of the summary AE on loading cycle number with the moment of the rise of the fatigue crack.

2. To finish the model of quantitative evaluation of the rise of a fatigue crack by the summary AE in a loading cycle.

3. To work out a procedure of using AE method when conducting bench tests of aviation units.

4. To work out a method of fatigue crack early detection on the basis of the AE effect.

Investigation procedure

To investigate regularities of fatigue fault accumulation process there was conducted cyclic loading of the objects tested with synchronous recording of the load applied and AE signals till the rise of a fatigue crack of a specified size. After that the fatigue testing was stopped and increasing load was applied till the destruction of the object of the test. Further there was conducted fractographic investigation of the fracture and comparison of data obtained with AE signals.

For conducting the investigation there were used test benches of the Riga "AVIATEST LNK" Scientific Experimental Center).

- A dynamic channel specially worked out for the cyclic testing of strengthened surface titanium specimens. Specimen loading frequency – 30 Hz. WPM testing machine, finished at AVIATEST. It was used for monotonous tension of the titanium specimens till the destruction after the termination of the fatigue tests.

- Test bench of Tu-154 plane landing gear principal support of. It is possible to realize at the bench various loading programs, setting loads along 3 axes X, Y, and Z. For the realization of a loading program there may be involved up to 18 loading channels.

- Test bench of propeller pitch control arm of EH-101 helicopter. For setting loads there are used 4 loading channels that realize the loads acting on the pitch control arm in the operation.

For conducting fractographic investigation there was used an electron microscope of Carl Zeiss firm manufacture, analogous to that one on which there are investigated elements of aviation units destructed in the operation.

Scientific novelty

1. There are investigated regularities of the rise of fatigue cracks and of getting the correspondence of alpha- criterion to the moment of the rise of the fatigue crack. It is proved that the first break on the dependence of the summary AE on loading cycle number («α» criterion) is identified as the moment of the conception of a fatigue crack of a microscopic size. If at the initial stage of the testing there may be observed a few breaks, a few α angles, on the dependence of the summary acoustic emission on loading cycle number, then the number of α angles corresponds to the number of fatigue microcracks formed.

2. Investigated a model of quantitative evaluation of the rise of a fatigue crack by the summary AE in a loading cycle.

Shown that at the stage of the rise of the crack it is necessary in the calculation to take into consideration only that summary AE in each loading cycle, which falls to the stage of the accelerated growth of the summary AE on loading cycle number («α» criterion).

3. On the ground of the AE method there has been worked out a procedure of evaluating fatigue crack growth at unit cyclic testing, protected by Latvian Republic patent №13853. The evaluation of fatigue crack growth in the units is carried out in the process of cyclic testing of those with sign-permanent load. In the process of the testing there are synchronously registered values of AE signal level and the load. At that there is determined AE signal position in each loading cycle. The moment of the achieving by the crack of the specified size is evaluated by the results of the stabilization of both AE signal intensity level and AE signal position in the loading cycle.

Basis Theses for Defense

- The identification of moment of the rise of the fatigue crack by «α» criterion
- The procedure of using AE method when conducting bench tests of aviation units.
- The method of fatigue crack early detection on the basis of the AE effect.

Practical significance of the work and the introduction

The results of the investigation may be used for the control of the rise and growth of fatigue cracks when testing both various load-bearing aviation units and other kinds of machinery, e.g. railroad one.

The results of the work have been introduced at the "Aviatest LNK» SIA enterprise in the form of a procedure "Procedure of AE control at test-bench fatigue testing of load-bearing units"

Work approbation

On the ground of the investigation conducted there has been obtained a patent of the Latvian Republic. Patent № 13853 "Method of fatigue crack growth evaluation in the process of unit cyclic testing". A. Urbah, C. Doroshko, M. Banov, A. Nasibullin. The patent is valid in the Latvian Republic for 20 years since. 06.11.2008.

The results of the work were used when carrying out RTU project **№ZP-2008-21** „Aviation unit fatigue crack early identification and working out control methods during bench testing" (2008.-2009) and RTU project FLPP-2009/52 „Rūpniecisko ventilatoru vibroakustiskā diagnostika" (2008.-2009.g.g.);

Proceedings at conferences:

1.International Conference „Non-Destructive Testing and Diagnostics – 2006" Lietuva, Viļņa, 2006g. 26.maijs, „Undercarriage fatigue test control by acoustic emission method"

2.12th International Conference "Transport Means 2008", Lietuva, Kauna, 2008g. 23.oktobris, "Acoustic emission monitoring of landing gear fatigue testing."

3.International Conference „Non-Destructive Testing and Diagnostics – 2009", Lietuva, Viļņa, 2009g.28.maijs, "The helicopter's MI-26T tail and fin booms stressed state under static loading"

4. 48. RTU studentu zinātniska un tehniska konference. TMF, Aviācijas institūts, 2007g. 14.aprīlis, „Noguruma plaisas rašanās un attīstības kontrole ar akustiskās emisijas metodi."

5. Zinātniskā konference „K. D. Mirtovam 100 gadi". Rīga, RTU, TMF, Aviācijas institūts, 2008g. 25.janvaris, „Акустическая эмиссия как метод неразрушающего контроля шасси самолета Ту-154Б при стендовых испытаниях."

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7. RTU 50. starptautiskā zinātniskā konference. TMF, Transportmašīnu Tehnoloģiju Institūts. „Akustiskās emisijas metodes pielietojums helikoptera EH-101 propellera soļa vadības roksviras noguruma pārbaudēs."

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2. Nasibullins A., Banovs M., „Noguruma plaisas rašanās un attīstības kontrole ar akustiskās emisijas metodi.*"*, 48. RTU studentu zinātniskās un tehniskās konferences materiāli, 2007. gada aprīlī. – Rīga : RTU Izdevniecība, 2007. – 1.d.: Arhitektūra. Būvniecība. Datorzinātne. Elektrozinības. Mašīnzinības, 185 -185.lpp.

3. Banovs M., Feščuks J., Nasibullins A., Vinogradovs L. „Gultņu elektrodzinēja mezgla akustisko-emisiju diagnostika", RTU zinātnieskie raksti 6. sērija Mašīnzinatne un transports, intelektualas tranporta sistēmas, 26. sējums, RTU, Rīga 2008, 56-61 lpp.

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5. Urbahs A., Banovs M., Doroško S., Nasibullins A., Feščuks J. Leak control technology in pressure vessels // High Tech in Latvia 2008. - Rīga, LATVIJA: Latvia Technology Park, 2008. - 55.-55. lpp.

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7. Nasibullins A., Turko V. "The helicopter's MI-26T tail and fin booms stressed state under static loading". Ultragarsas. - №2 (64), 2009, 45.-47. lpp.

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10. Nasibullins A., Banovs M. “Acoustic Emission monitoring of fatigue crack origination during titanium specimens tests .” RTU zinātnieskie raksti 6. sērija Mašīnzinatne un transports, 34. sējums, RTU, Rīga 2010, 61-67 lpp.

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Subject of the work

In the first chapter of the work there are considered NT methods used when operating and testing aviation equipment. Analyzed possibilities of using that with taking into consideration the resolution and usability limits. Shown advantages and shortcomings of AE method in comparison with the methods considered.

Advantages of AE method:

- has low preparatoty work and control labour input, tens (hundreds) times less than for other NT methods. The method does not require continuous scanning of the surface, i.e. allows to install sensors on the object investigated locally, which signigicantly decreases production expenditures: minimal removal of the insulation, minimal cleaning of the surface).

- Is global by control volume. By way of installing a few sensors there is carried out the control of the whole object with the determination of places of the rise and development of defects (detection and ranging mode).That allows to use the given method for controlling inaccessible surfaces as well as to realize continuous control (monitoring) of the object during the functioning and to proceed from periodical technical inspections to the operation of the object by its actual technical condition.

- Allows to diagnose an object in whole, not putting it out of the existing operational mode or putting it out for some minimal time, which gives obvious economics advantages in comparison with traditional NT methods requiring the termination of the operation of the object for conducting control.

- AE-control method ensures the detection and registration of just developing and therefore really dangerous defects and brings about the classification of those not by size, but by the extent of danger. That means, in particular, that some, e.g. round, defects the size of which exceeds the rejecting level of NT traditional methods, may get in the category of not-dangerous ones when using AE control, as they exist, not developing during the operation of the object. This allows to well-groundedly cancel the stoppage of the object and repair works, which in a number of cases just lower the reliability of the object.

- Possesses universality with regard to the choice of the object diagnosed, i.e. may be used without any limitation for the diagnostics of any objects where there may be ensured pressure (load) change for initiating possible defects.

In the second chapter there are described procedures of conducting the tests and AE equipment used. When testing, there were used three sets of measuring AE instrumentation. The first of them, on the basis of АФ-15 instrument, the second on the basis of PAC 3000/3004, the third one - P-DAQ/T-DAQ measuring system. To solve the task put, it is necessary to conduct synchronous recording of AE and the applied load signals Available AE instruments. did not have such a possibility. To solve the given task there was carried out the modernization of АФ-15 instrument.

On Fig. 1 there is shown a functional diagram of the connection of АФ-15 instrument to a personal computer.

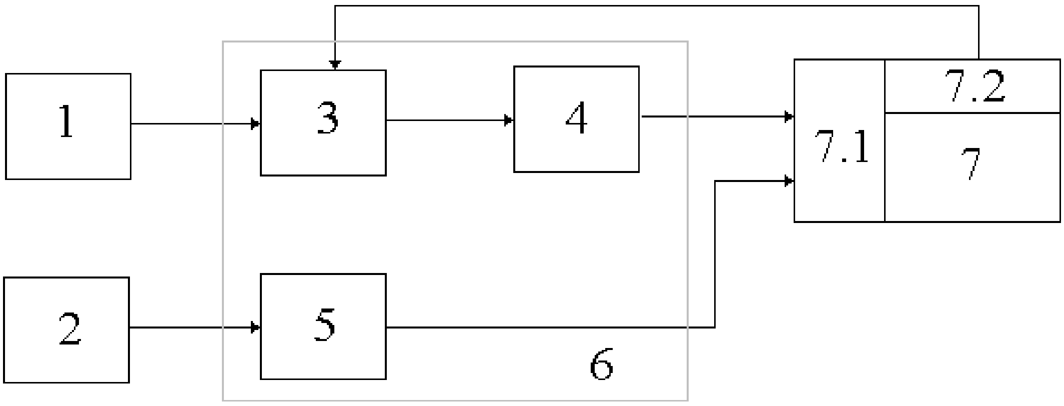


Fig 1. Functional diagram of modernized AE signal measuring complex on the basis of АФ-15 instrument. 1 - АФ-15, 2 - load sensor, 3 – controlled pulse counter-divider, 4 – buffer stage, 5 – matching amplifier, 6 - matching device,7 - personal computer, 7.1. ADC Lcard L-783, 7.2 - DAC Lcard L-783.

For registering AE and load signals there was written «Akusto» program in C++ programming language. In Borland 2007 working-out environment there was worked out a user interface. For mathematical treatment of signals recorded there is used Powergraph program.

As a result of the work conducted there were removed principal shortcomings of АФ-15 instrument. AE measuring complex obtained on the basis of АФ-15 instrument, meets modern requirements to AE equipment.

On Fig.2. there is shown a standard diagram of the connection of AE measuring instruments when conducting tests.

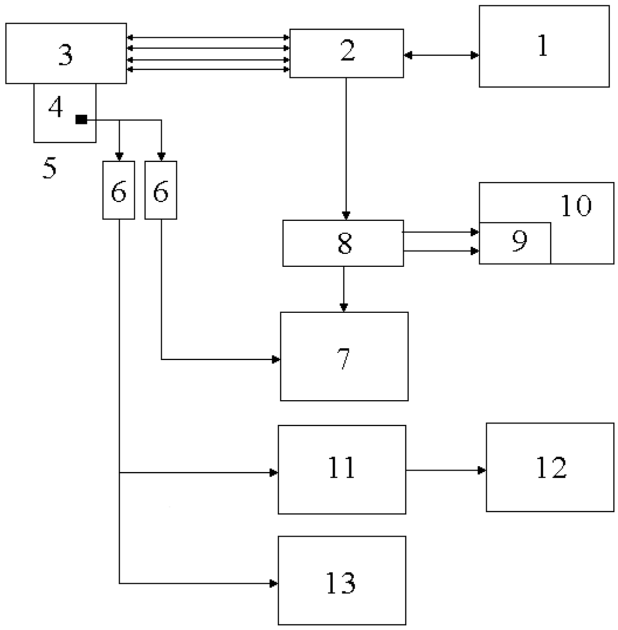


Fig.2. Diagram of AE measuring equipment connection. 1 - Control system computer, 2- Control system, 3- Hydraulic cylinder for setting loads, 4 – Test object, 5- AE sensor, 6 – Preamplifier (PA), 7 - АФ-15 instrument, 8 – Matching device, 9 - АЦП Lcard L-783, 10 – AE registering computer, 11 - P-DAQ/T-DAQ measuring system,12 -notebook, 13 - PAC 3000/3004 measuring system.

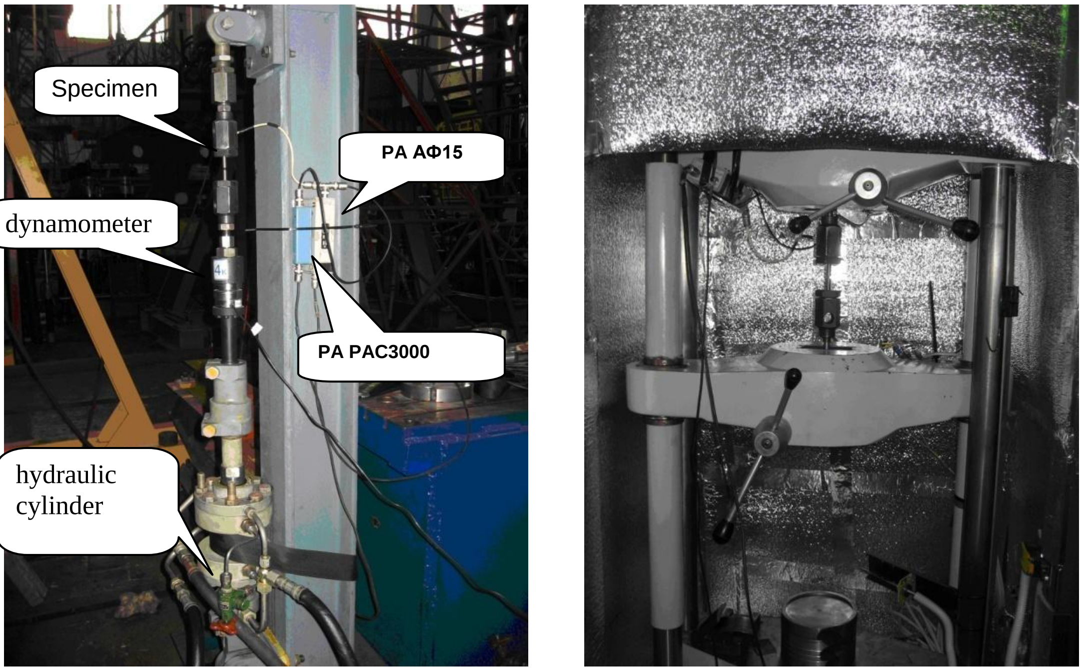
Test bench and a procedure of testing titanium specimens strengthened from the surface.

For carrying out fatigue tests there was mounted a special unit presented on Fig. 3a. The unit consists of a frame, hydraulic cylinder for load setting, and strain gauge dynamometer (U93 type, the manufacturer the company HBM) for monitoring the load applied.

After going through the fatigue testing unit, the specimens were subjected to monotonous tension up to the destruction. For this objective there was used a WPM testing machine worked out and finished at AVIATEST (see Fig.3b).

Specimen loading was carried out according to the movement along with the monitoring of the load applied.

To the specimens tested there was applied cyclical fixed-sign load. Loading frequency for all the specimens was 30 Hz. Applied load value for each specimen was corrected according to the results of the previous tests. For the purpose of the identification of the moment of abrupt increase of summary AE count at the cyclic loading with the changes of the inside structure of the material, specimen testing was stopped after the registration of angles on the diagram of the dependence of total acoustic emission on the loading cycle number, and the specimens were subjected to monotonous tension up to the destruction.



a b

Fig.3. Titanium specimens testing unit (a), WPM testing machine (b)

After that there was conducted a fractographic investigation of the fracture. Specimen tension speed was 0,005 mm/s for the tension process duration to be about 5 min. Such a little loading speed was chosen to give the material a possibility to react to the tension in all the areas where it had tension concentrators, and, first of all, where there had supposedly been formed the surface of a microcrack.

Test bench and a procedure of testing landing gear principal support of Ty-154 plane.

To test the landing gear there was used bench complex of the Riga Scientific Experimental Centre“AVIATEST LNK”. The bench has been certified by Latvian National Accreditation Bureau in accordance with the requirements of LVS EN 450001 European standard for fatigue testing of aircraft parts and units and is the only bench of such kind in Latvia.

Depending on the tasks stated, when conducting bench tests there may be realized various loading programs. These programs may differ by the number of loading channels used, direction and value of loads applied. A diagram of load action upon landing gear support is presented on Fig 4.

General view of a bench for landing gear fatigue testing is presented on Fig.5. The principal support of the landing gear is placed on it in a turned over position and is fastened to floor rails with the help of regular brackets. Test object loading was brought about with hydraulic cylinders placed on a special frame; hydraulic cylinder rods were connected with various points of landing gear for creating set load spectrum.

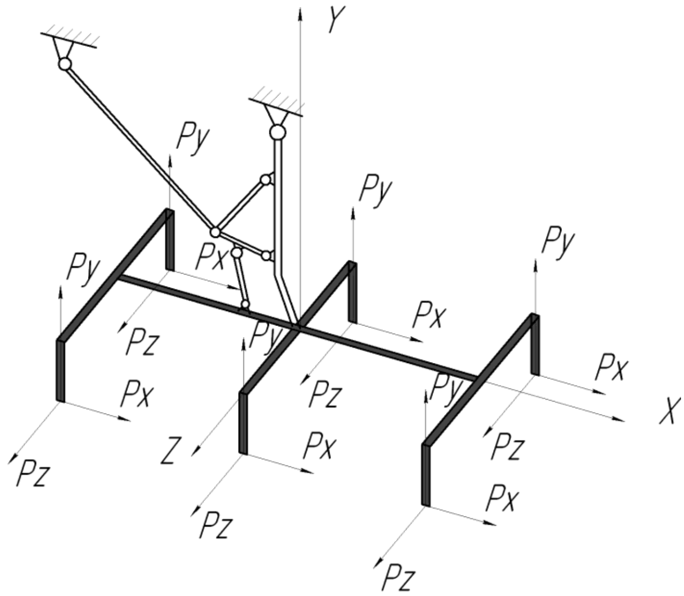


Fig.4. Diagram of load action upon landing gear principal support

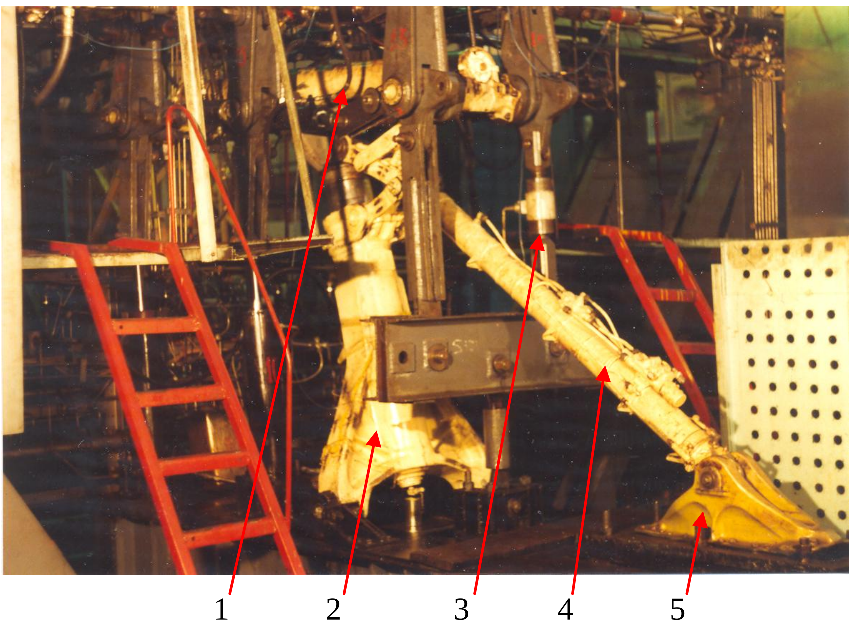


Fig.5 General view of loading gear test bench. 1 - truck; 2 - shock-absorber; 3 – loading system hydraulic cylinder; 4 - stay-hoist; 5 – bracket

When testing, it was necessary to get a fatigue crack from a concentrator applied on the inside surface of shock-absorber rod. To reduce crack growth time, there was chosen the following loading program – the loading was produced by pulsing side forces P_z= 0…10.6 tons (Fig.6) with constant vertical loads P_y= 45.0 tons. The application of P_z side forces with regard to the saw cut was chosen so that it had to cause saw cut opening.

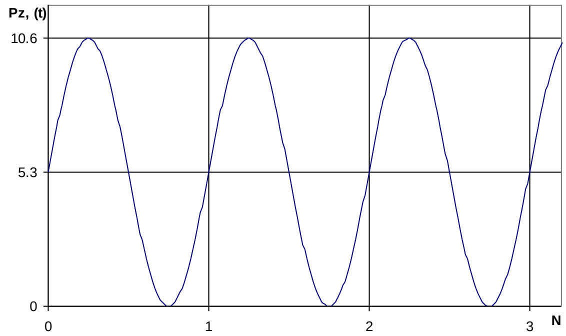


Fig.6 Pulsing side force loading($\mathbf{P_z}$ = 0…10,6 tons).

Test bench and procedure of testing propeller pitch control arm of EH-101 helicopter.

For testing propeller pitch control arm there was used a bench complex of the Riga "AVIATEST LNK" Scientific Experimental Centre.

For applying the load specified with the testing program there are used four hydraulic cylinders: HF - horizontal force, VF – vertical force, RF – pitch link force, CF – centrifugal force. On Fig.7 there is presented a diagram of a bench for testing propeller pitch control arm of EH-101 helicopter, with the indication of the direction of load application for each hydraulic cylinder. Test object loading was conducted cyclically. Each loading cycle was of trapezoidal shape and consisted of four loading stages. See Fig 8.

Stage 1 – loading preparation (t=1c, HF=0kN, VF=-29,43kN, RF=0kN, CF=0kN), Stage 2 – arrival at the specified load (t=1c), Stage 3 – keeping the load(t=1c, HF=-44,14kN, VF=39,24kN, RF=42,18kN, CF=462kN), and Stage 4 - unloading(t=1c). Total duration of one loading cycle constitutes 4 sec.

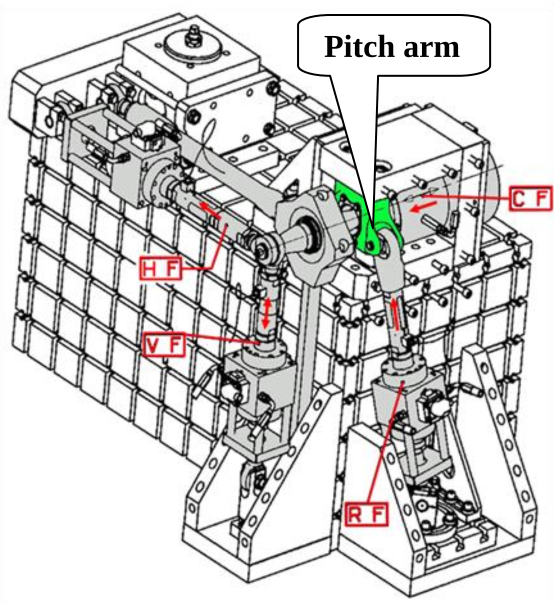


Fig.7 Diagram of a bench for conducting fatigue tests of propeller pitch control arm of EH-101 helicopter.

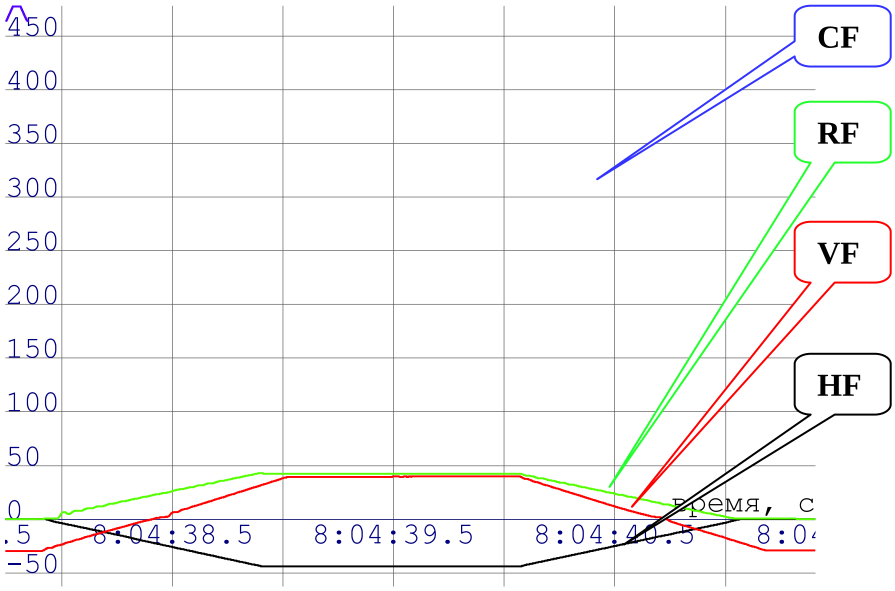


Fig.8 Cyclogram of load application to propeller pitch control arm of EH-101 helicopter.

In the third chapter there is considered a model of quantitative evaluation of the forming of a fatigue crack by the summary AE in the loading cycle, it is shown that in the model at microcrack conception stage, in the calculation it is necessary to take into consideration only that summary AE in each loading cycle, which falls to the stage of summary AE accelerated growth on loading cycle number («α» criterion). There is proved the correspondence of the first break on the diagram of the dependence of the summary AE on loading cycle number with the moment of the rise of the fatigue crack.

In the process of cyclic loading, as it is known, there are happening irreversible material structure changes. .At the present time it is universally adopted that fatigue damaging process is connected with the development of plastic deformation preparing the rise of submicrocracks. They gradually grow up and turn into microcracks which further on increase up to the size of macrocracks visible to the naked eye.

According to kinetic durability conception, each act of deformation or destruction is accompanied by the rupture of interatomic connections with release of some energy.

The accumulation of the damages and the collective rupture of the interatomic connections may initiate an acoustic pulse sufficient for its registration by the converter. Therefore, each act of material structure damage is corresponded by a primary resilient pulse, the process of radiation of which presents a so called "AE act", and measuring AE act sequence speed will allow to evaluate destruction process going speed.

Let's assume that AE pulse number generated during a cycle, is proportional to that part of potential energy U released at the progress of the crack in this U potential energy cycle, which turns into A_k kinetic energy of environment movement causing a reaction of AE signal converter.

The presence of a definite connection between the kinetic energy radiated at the crack progress, and crack growth speed, was determined on the basis of the following analysis: Let crack surface receive in a certain loading cycle δS. This crack increment causes potential energy release.

$$\delta U = \frac{1-\mu^2}{E} K^2 \delta S \tag{1.1}$$

Where E – material resilience module, μ- Puasson coefficient, K – tension intensity coefficient (TIC) (it is supposed that the crack develops according to normal separation mechanism).

The energy released goes in part for material plastic deformation connected with the advancement of the plastic area. This share of energy is proportional to the volume of the layers plastically deformed, immediately adjoining newly formed surface.

$$\delta A_p = \overline{\sigma}_i \overline{\varepsilon}_i * 2h\delta S \tag{1.2}$$

Where $\overline{\sigma}_i$ and $\overline{\varepsilon}_i$ - average tension and deformation intensities in the layers specified,

2h – layer thickness

If to assume an extent dependence of stretching diagram of the following kind: $\sigma_i = \sigma_0 \left(\frac{\varepsilon_i}{\varepsilon_0}\right)^m$,

where m- strengthening index, σ0 – yield point, and $\varepsilon_0 = \frac{\sigma_0}{\mathrm{E}}$, then deformation intensity distribution in the plastic area in dependence on r distance from the top of the crack might be approximated with the expression:

$$\varepsilon_{i(r)} = \varepsilon_0 \left(\frac{r_p}{r}\right)^{\frac{1}{1+m}} \tag{1.3}$$

where r_p – plastic area size.

As a result, we shall determine average values of plastic area tensions and deformations according to the expressions

$$\overline{\sigma}_i = \frac{1}{r_p} \int_0^{r_p} \sigma_i(r) dr = (1+m)\sigma_0 \tag{1.4}$$

$$\overline{\varepsilon}_i = \frac{1}{r_p} \int_0^{r_p} \varepsilon_i(r) dr = \frac{(1+m)}{m} \varepsilon_0 \tag{1.5}$$

As $h \sim r_p$, $\delta S = t\delta l$, then using(1.2), (1.4), (1.5), we receive for a plate of t thickness

$$\delta A_p = \beta \frac{(1+m)^2}{m} \frac{\sigma_0^2}{E} r_p t \delta l \tag{1.6}$$

Where β – a constant, δl – crack length increment

For approximate estimate we shall assume

$$r_p = \frac{K^2}{2\pi(1+m)\sigma_0^2} \tag{1.7}$$

then

$$\delta A_p = \frac{\beta}{2\pi E} \frac{1+m}{m} t K^2 \delta l \tag{1.8}$$

If we put (1.1) и (1.8) into energy equation

$$\delta U = \delta A_k + \delta A_p$$

with subsequent transition to continuous functions on n cycle number , then as a result we shall obtain an expression for the determination of cycle kinetic energy

$$\frac{dA_k}{dn} = \beta_0 t K^2 \vartheta \tag{1.9}$$

Where $\vartheta = \frac{dl}{dn}$ - microscopic crack growth speed equal to its progress in a specific cycle, β – a constant defined with an expression $\beta_0 = \frac{2\pi m(1-\mu^2)-\beta(1+m)}{2\pi m E}$

Having assumed that Paris law is observed as well at little speeds of fatigue crack growth, if to take in it the average microscopic speed, then K may be expressed in the form of

$$K = \frac{1}{C} \vartheta^{\frac{1}{\alpha}} \tag{1.10}$$

Having assumed extent dependence

$$N_{\Sigma ц} \sim \left(\frac{dA_k}{dn}\right)^C \tag{1.11}$$

We shall get the sought for connection between AE summary count for a $N_{\Sigma ц}$ cycle and average microscopic speed of crack growth υ.

$$N_{\Sigma ц} = \beta_1 \left(1 - \beta_2 \vartheta^{\frac{2}{(1+m)\alpha}}\right) \vartheta^{\left(1+\frac{2}{\alpha}\right)} \quad (1.12)$$

where β_1 и β_2 - experiment defined constants, α and C - constants of the material.

(1.12) dependence may be written in a simplified form

$$\vartheta = \frac{B}{t^C} N_{\Sigma ц}^{\frac{\alpha}{\alpha+2C}} \quad (1.13)$$

where B – a constant depending on resilient constants, strengthening index and Paris law constants.

The relation obtained practically should not depend on crack type, as the latter determines mainly the character of the plastic deformation . As to the destruction process and AE signals initiated by it in the material, the character of the rupture of the connections between the banks, when forming new crack surface, is determined only by the properties of the material.

In the model considered above (1.13) there appears such a parameter as summary AE in $N_{\Sigma ц}$ loading cycle. Hence arises a question: Which loading cycles are to be taken into consideration when calculating crack growth speed by the summary AE in a loading cycle? There exists a theory that fatigue crack development is of step character. The beginning of these stages is determined by «α» criterion – the breaks on the diagram of the dependence of summary acoustic emission on loading cycle number. Therefore it may be supposed that when calculating fatigue crack growth speed, it is necessary to take into consideration only those loading cycles, which fall to summary AE accelerated growth stages.

It is considered as well that the first «α» criterium is the first break on the diagram of the dependence of the total acoustic emission on the number of loading cycles - is one of the criteria of the arising of a fatigue crack when using AE method . However it has not yet been proved up to this day that immediately after the specified criterion had been fixed on the acoustogram, there has formed a crack in the metal.

To corroborate these facts there were conducted fatigue tests of a number of specimens of BT3-1 titanium alloy, strengthened from the surface, for investigating the mechanism of the arising of fatigue cracks and obtaining the correspondence of alpha criterion with the moment of the arising of a fatigue crack

Geometry and appearance of specimens tested is presented on Fig.9.

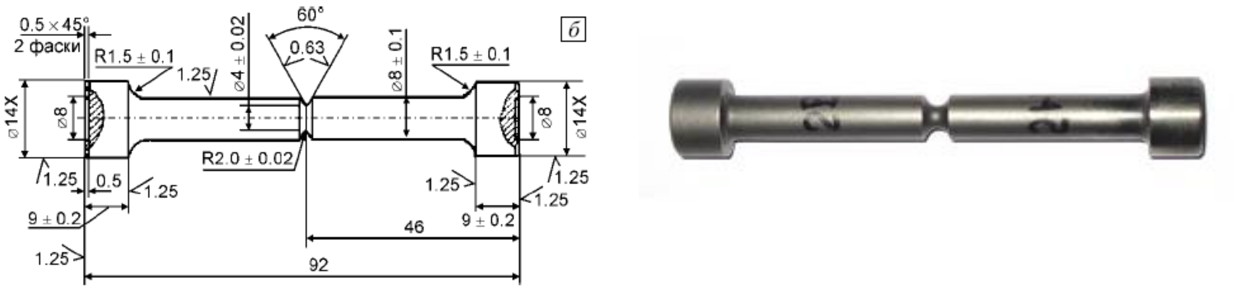


Fig.9 Geometry and appearance of specimens tested

The results of AE control of the conception of fatigue cracks in the specimens, were presented in the form of diagrams of dependence of the total AE on the number of loading cycles, and fragments of synchronous record of AE signal intensity and the load applied.

One of these diagrams is presented on Fig.10. The results of the fractographic investigation of the fracture of this specimen are presented on Fig.11.

As a result of the fractographic investigation of specimen fractures it was stated that in the specimens there was formed a typical fracture with plastic deformation bevels, which is usually observed at elastic failure of specimens being monotonously stretched. Flat elastic fracture in the middle and plastic deformation bevels along the surface of the specimen.

It was discovered that in the middle part of all the specimens there had been formed a fracture relief with concentric pits. An analogous relief in the form of elongated pits was formed along the plastic deformation bevels.

At the same time, on each specimen near the surface or at a certain distance from the surface there were discovered some small areas of quasi-brittle destruction of the material. Just these areas of the fracture reflect the fact that in the material of the specimen there has already arisen a zone of material having lost its strength (weakened), which was being registered by "α" criterion on the ground of the acceleration in the accumulation of summary AE signals. Thus the break on the dependence of total AE on loading cycle number ("α" criterion) is identified as the moment of the conception of a fatigue crack of microscopic size.

In some cases in the process of cyclic loading, on the dependence of summary acoustic emission on loading cycle number there may be observed a few breaks, a few α angles (see Fig. 10). The results of fractographic investigation of the fractures of these specimens showed that the number of α angles corresponds to the number of fatigue microcracks arisen (see Fig.11).

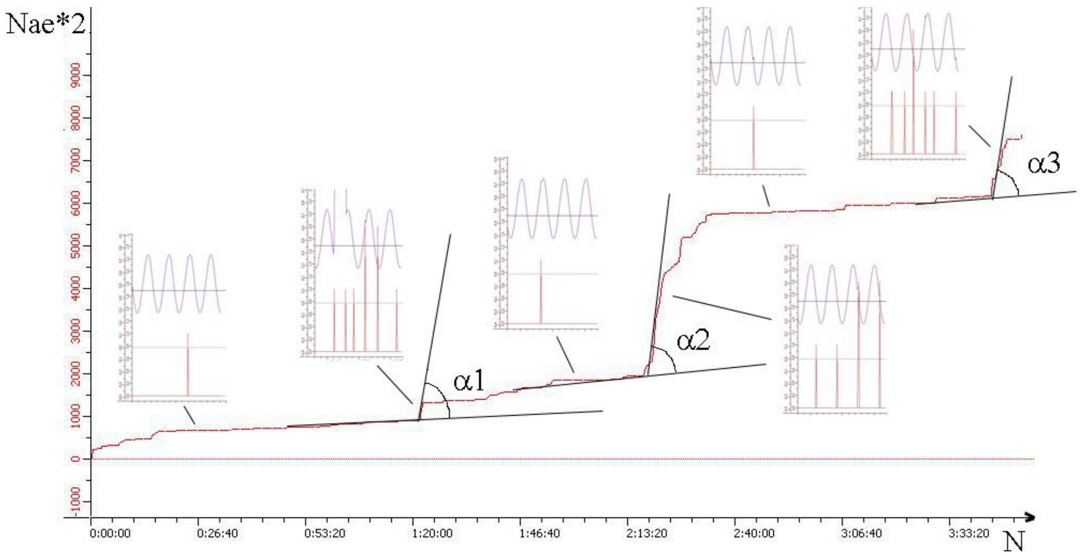


Fig.10 Diagram of dependence of N_{AE} summary AE on N loading cycle number (Specimen operating 415104 cycle)

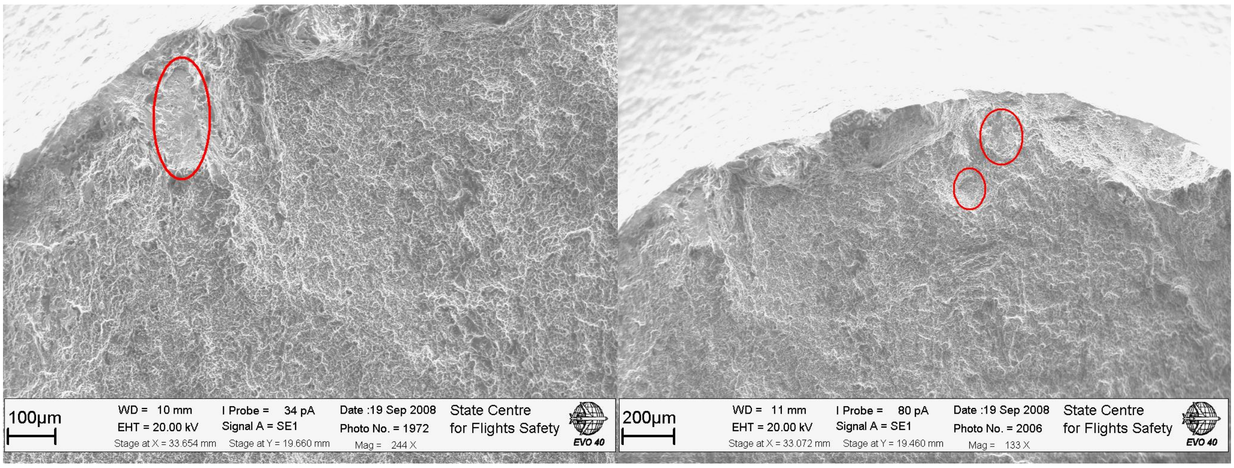


Fig.11 The result of fractographic investigation of the fracture of specimen

In the fourth chapter there is described fatigue testing of landing gear principal support of Ty-154 plane. Testing object technical state control was brought about by way of AE method. On the ground of the experiment carried out there was worked out a procedure of the use of AE method when testing load-bearing aviation units and a procedure of the evaluation of fatigue crack growth at unit AE method cyclic testing. There was conducted the approbation of procedures worked out when testing propeller pitch control arm of EH-101 helicopter.

When testing landing gear principal support, at which there were investigated fatigue characteristics of brace-hoist lugs, there arose C-shaped through crack on the mirror of shock-absorber rod (see fig 12.). Crack length at the moment of discovering it was 162 mm.

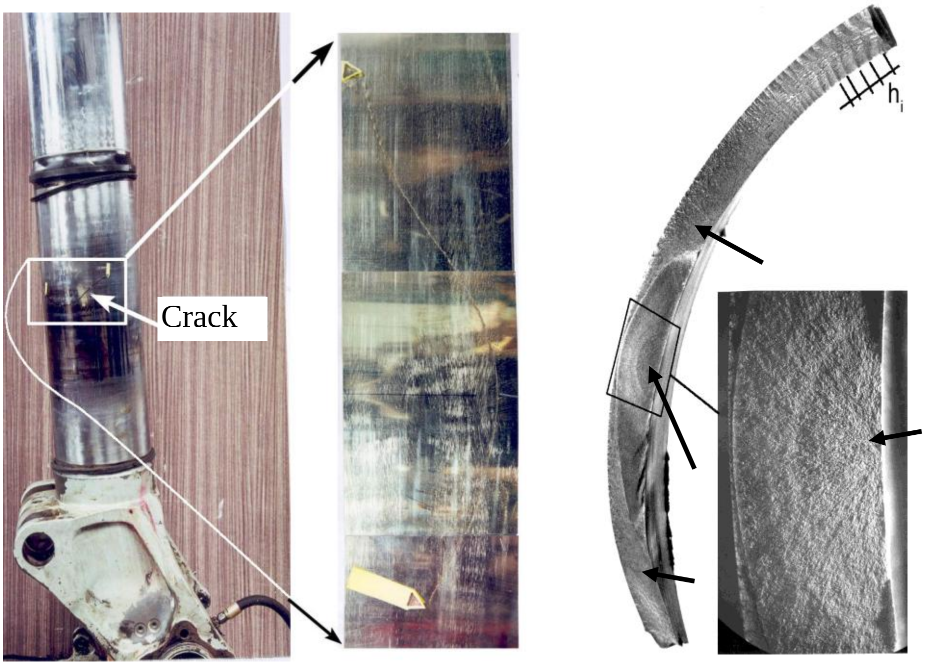


Fig.12 Shock-absorber rod crack

By way of fractographic investigation it was discovered that the crack is of fatigue character and its centre had been local intergrain destruction of the material.

In connection with high danger of the destruction of shock-absorber rod in the operation, there were continued investigations for evaluating the development of such a defect and possibilities of discovering it. For this purpose in the design of shock-absorber rod was introduced an artificial defect – a concentrator. The concentrator was introduced in the shock-absorber rod at a place where a fatigue crack was arising in the process of the previous fatigue testing.

It was a saw cut of 21-mm length and 0.8- mm width (Fig. 13).

As a possibility of using traditional methods of non-destructive testing without disassembling was limited (there was conducted only periodic US testing after each 200…400 loading cycles, to carry it out, the testing was stopped and the rod was pushed out of the dhock-absorber cylinder),so as the principal method of fatigue crack rise and growth control was used AE method.

Fig.13 Saw cut concentrator (obtained after the destruction)

As AE sensor there was used a piezoelectric transducer. Piezoelectric transducer was glued on shock-absorber rod mirror at a place protruding out of the cylinder (Fig. 14).

For the synchronization of AE-information with loading process, there was used a bonded strain gauge glued in the area of maximal sensitivity to a load applied.

Fig 14. Placing piezoelectric transducer and strain gauge on shock-absorber rod mirror.

At 3550 loading cycle running in the rod of the shock-absorber there was supposedly recorded a fatigue crack of 0.6…1.7 mm size. For confident getting a fatigue crack the testing was continued during 1000 units (the total running constituted 4500 cycles) with US testing after each 200 loading cycles. Estimated crack size after the testing termination constituted 0.2…1.8

mm. After the opening of the fracture it was revealed that the crack had grown through from the both ends of the saw cut for a value of 0,6…0,7 mm.

Fractographic analysis results showed that the main crack had arisen from a multitude of sites along the top of the cut.

At the initial stage, for the depth of about 30 micron, there hadspreaded a lot of cracks having arisen independently. They formed a cascade of steps that indicate the convergence of autonomous areas arisen in the rod along the concentrator. A more detailed analysis, at a greater microscope magnification, shows (Fig. 15) that at first there was taking place crack cascade development in the limits of mesotunnels, after which crack growth speed decreased. From the border of sharp crack growth decrease there took place a repeated intensive development of the destruction, which is expressed in the increase of fracture roughness. On Fig. 15 there are shown with arrows the sizes of the first two crack growth areas with different speed up to the borders of destruction development acceleration change.

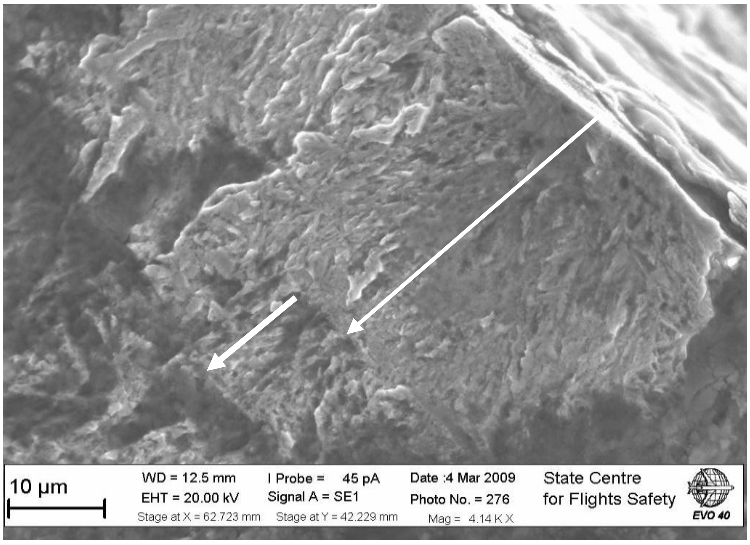


Fig.15. Fragments of fracture at the initial stage of landing gear support destruction

The investigation conducted shows that there were at least two sharp transitions in conditions of shock-absorber rod crack development: (1) initial crack formation for a depth of about 20 micron with the subsequent stop of the cracks, (2) further rise and development of cracks in autonomous mesotunnels. Further on there was taking place the uniting of wide mesotunnels in one arterial crack. In the process of the growth of the main crack there were taking place its accelerations in the middle part, where the depth of the crack was maximal, and on its edges.

A diagram of the alteration of N_{AE} summary AE in dependence on cycle number, produced by AΦ-15 instrument, is shown on Fig. 16.

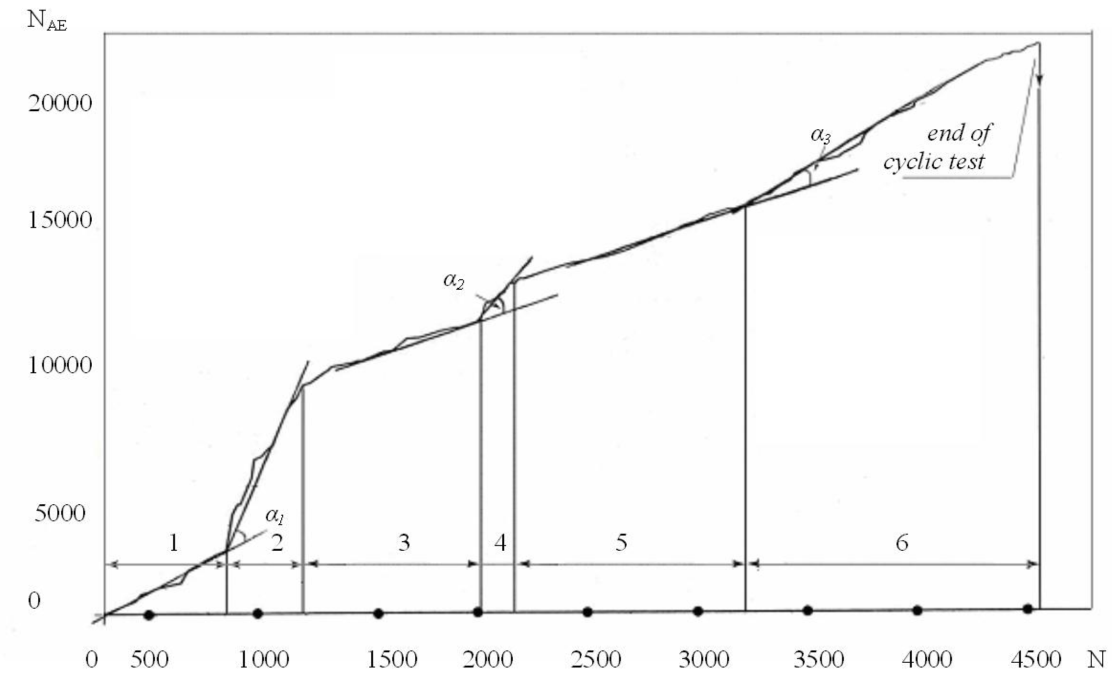


Fig.16. Dependence of N_{AE} summary AE on N loading cycle number

On the diagrams there are clearly discerned 3 stages with slow (1, 3, and 5) and 3 stages with rapid (2, 4, and 6) accumulation of AE pulses. 1, 3, and 5 stages are characterized with sporadic appearance of AE signals; At 2, 4 , and 6 stages (these areas are designated with α_1, α_2, and α_3, angles characterizing N_{AE} summary AE changing speed AE pulses appear practically in each loading cycle, but for each stage there are their own distinctions of their appearance. Fragments of synchronous load and AE signal recording are presented on Fig 17.

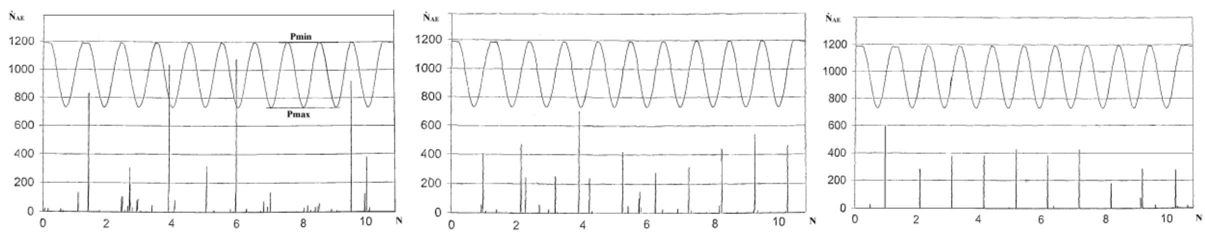


Fig 17. Synchronous record of P load and.AE intensity change

a - $\boldsymbol{N'}$ > 1200 cycles, b - $\boldsymbol{N'}$ > 2000 cycles), c - $\boldsymbol{N'}$ > 3000 cycles

It should be noted that crack development process is of discrete character, i.e. crack slow growth stages where the crack grows in separate loading cycles, alternate with its rapid growth stages – the crack increases in all the cycles of these stages. The alternation of these stages may be explained with the processes of the accumulation and release of energy in interatomic and interdislocation connections: the process of the release of the energy accumulated (of interatomic and interdislocation connection force work) is realized in crack growth.

Thus, at the initial stage of the testing (Fig16. stage 1), it is the most probable that the AE signal accumulation is connected with the initial motion of separate dislocations not requiring significant energy for this motion. It is probable as well that dislocation areas may be situated in various parts of investigation object. But as a whole it is clear that at the given stage there is taking place energy accumulation process and increasing tension distribution nonuniformity in dependence on initial defects of investigation object material structure. As the most nonuniformity of material properties is localized in the area of the concentrators (constructive, artificial or arisen in the process of the operation of the object), then just here there arises as well the most tension distribution nonuniformity.

At the achieving of the critical value of tensions, when they surpass forces supporting atomic lattice of the material with dislocations in stable state, there happens the rupture of the connections between the dislocations, and their motion – this is the moment of the rise of a fatigue microcrack.

Dislocation motion process is accompanied by intensive generation of AE signals, which may be evaluated by a parameter named α- criterion on Fig. 16, stage 2, characterized by α_1 angle.

At that, it should be taken into consideration some peculiarities: first, the crack grows practically in each loading unit (cycle), second, a microcrack grows due both to cyclic loading at this moment and the energy accumulated at the stage 1, and, third, there is possible the rise of two or more microcracks, which is reflected by a few breaks at this stage.

Analysis of AE behaviour in loading cycles testifies of the rise of two powerful AE ejections in some cycles. This phenomenon along with the α- criterion may be used for the indication of the rise of a microcrack

When dislocation cohesive forces turn out to be greater than loads striving to continue their motion, fatigue crack growth begins braking and its development practically stops – this is the next stage of defect development (Fig 16, Stage 3). Like at the initial stage, loading energy is spent mainly not on the crack advancement work (the crack grows only in some individual loading cycles), but is accumulated mainly in dislocation areas around the crack.

Further the process recurs: when achieving a new critical state, the crack starts and once more begins to rise. On fig.16. this is stage 4, characterized by α_2 angle. A peculiarity of the given stage is the fact that the crack grows in each loading cycle. Further once more there follows braking stage when crack development speed is sharply reduced, stage 5 on Fig.16.

In the general case, such stages of stopping and subsequent growth of the crack may be a few – that depends on the characteristics of the material, the extent of its damaging, the level and character of the loads acting, etc. Sometimes it is hard enough to discriminate stages of stopping and of the subsequent growth.

A peculiarity of this stage (or stages) is the transformation of a microcrack into a mesocrack. It should be noted that the existing methods of the nondestructive testing do not allow to determine the presence of micro- or mesocracks in the material – they are identified only with methods for the realization of which it is necessary to destroy the part.

The conclusive crack development stage is characterized by the transformation of a mesocrack into a macrocrack - a macrocrack is defined as a crack that may be identified with nondestructive testing traditional methods (visual-optical, ultrasonic, magnetic powder, etc.) This is stage 6 on page 16, characterized by α_3 angle. The crack, like in the previous stages of the accelerated crack development, grows in each loading cycle.

Sometimes it is hard enough to determine an area of characteristic growth of N_{AE} summary AE and to register α-criterion. In this case, there may become useful $\boldsymbol{N'}$ AE activity (see, e.g. Fig.17). Macrocrack indication is especially important. The determination of this moment by α-criterion is hard enough: e.g., in a variant presented on Fig.16, $\alpha_3 < \alpha_2 < \alpha_3$.

Studying AE signal generation at cyclic fatigue testing, allows to recommend for the identification of the transformation of a fatigue mesocrack to a macrocrack, $\boldsymbol{N'}$ AE activity stability parameter in a loading cycle, which is characterized by two factors: AE intensity level stabilization and phase position in relation to $\boldsymbol{P}$ acting cyclic load (see Fig.17 c).

On the ground of the investigation conducted there was issued a patent №13853 of the Latvian Republic “Method of the evaluation of fatigue crack growth at unit cyclic testing”. The invention is related to measurement equipment and, in particular, to product control and diagnostics methods with the use of AE method. The method suggested may be used at fatigue testing of various units with sign-permanent cyclic load for the purpose of the evaluation of fatigue crack growth kinetics as well as at the control and diagnostics of technical condition of cyclic action machines. The evaluation of fatigue crack growth in units is conducted in the process of cyclic sign-permanent load testing of those.

In the process of the testing there are synchronously registered AE signal and load level values. At that there is determined AE signal position in each loading cycle. The moment of the achieving by the crack of the size set, is evaluated by the results of the stabilization of both AE signal intensity level and AE signal position in loading cycle.

Worked out “Procedure of using AE method when conducting aviation unit bench testing ” introduced at Riga «AVIATEST LNK» Scientific and Experimental Centre.

To confirm efficiency of the procedures worked out, it was necessary to carry out the approbation of those when conducting fatigue testing of a load-bearing unit. The approbation was conducted at the fatigue testing of propeller pitch control arm of EH-101 helicopter. Propeller pitch arm is a component part of swashplate - a mechanism in the system of controlling helicopter main lift rotor for changing blade setting angle.

To control the rise and growth of a fatigue crack there was used AE method as well as conducted periodical visual inspection of testing object. Propeller pitch control arm testing was conducted until the discovery of the fatigue crack by the visual method.

The fatigue testing was stopped at 136137 cycle running after the visual discovery of a fatigue crack of 15mm length. AE control results of technical condition of propeller pitch control arm of EH-101 helicopter are presented in the form of a diagram of the dependence of summary AE on loading cycle number, Fig.18, and fragments of synchronous records of AE intensity and the load applied (CF channel) Fig 19.

Analysis of a diagram of the dependence of summary AE on loading cycle number when testing propeller pitch control arm of EH-101 helicopter (Fig. 18) showed that it is very much alike the diagram of the dependence of summary AE on loading cycle number when testing Ty-154B landing gear principal support (Fig.16). The diagram presented on Fig.18, as well as the diagram presented on Fig.16, may be divided into six stages characterized by different summary AE growth speed. On the diagram (Fig.18) there are clearly discerned 3 stages with slow (1,3, and 5) and 3 stages with rapid (2,4, and 6) AE pulse accumulation.

Stages 1, 3 and 5 are characterized with sporadic appearance of AE signals; on stages 2, 4. and 6 (these areas are designated by α_1, α_2 и α3 angles, characterizing N_{AE} summary AE change speed). AE pulses appear practically in each loading cycle, but for each stage there are its own peculiarities of their appearance.

Analysis of the obtained AE data , results of fracture fractographic investigation as well as results obtained when testing Ty-154B landing gear principal support, allow to consider that the regularity of AE signal forming and fatigue crack development stages may be explained with the same processes as when testing landing gear principal support.

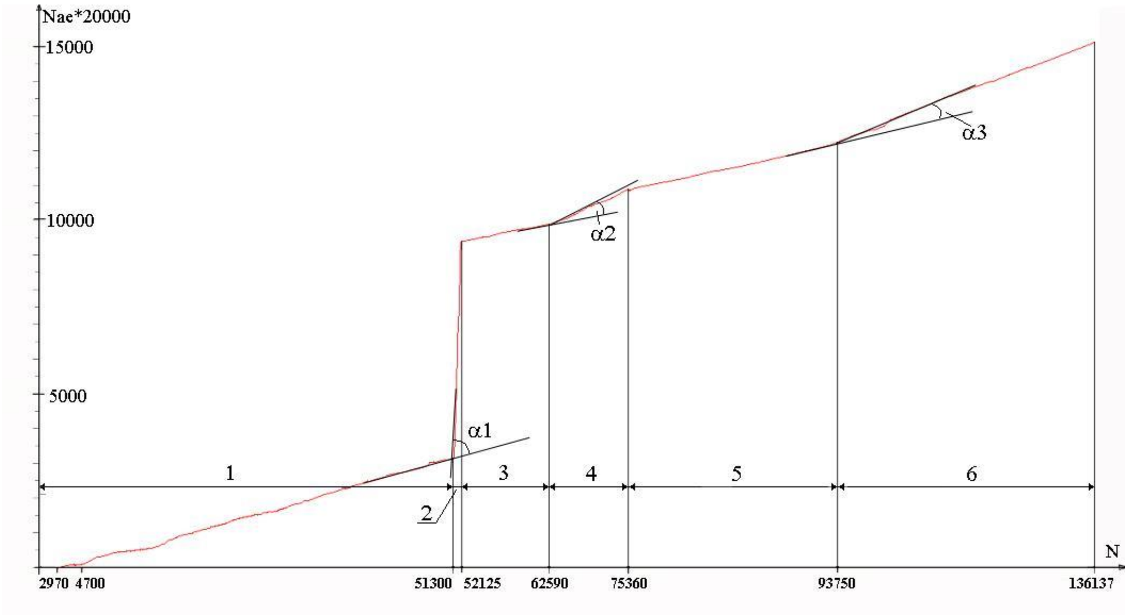
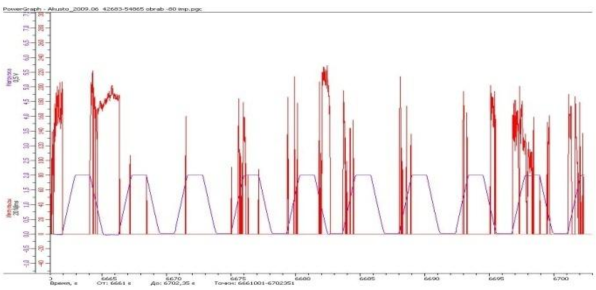
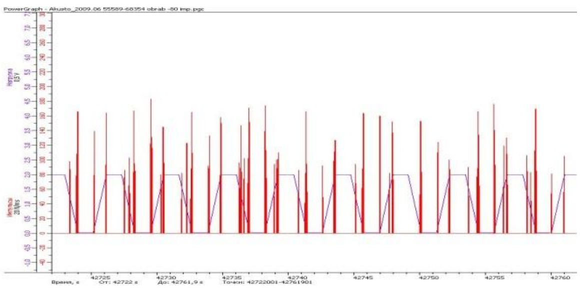


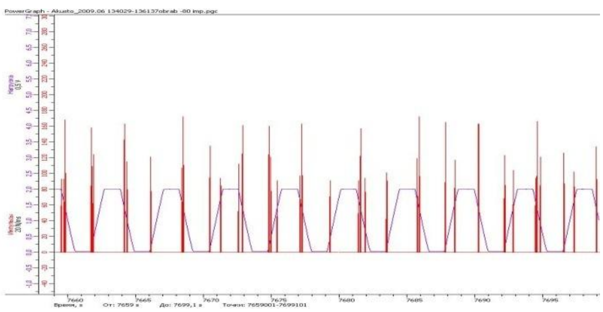
Fig.18 Diagram of the dependence of summary acoustic emission on loading cycle number



a



b



c

Fig. 21 Synchronous record of P load and $\boldsymbol{N'}$ AE intensity changing

a - stage №2, b. - stage №4. c - stage №6.

As it was said above, macrocrack indication is especially important. For the indication of this moment by AE method there was used “Method of evaluation of fatigue crack growth when cyclic-testing units” worked out on the ground of testing Ту-154Б plane landing gear principal support.

The moment of the transformation of a micro- or mesocrack into a macrocrack was evaluated by the results of the stabilization of AE signal intensity level and AE signal position in loading cycle.

On Fig. 19 there are presented fragments of synchronous records of AE intensity and load applied (CF channel) for stages №2, 4 and 6.

At stage №2 (Fig.18), this is the stage of fatigue microcrack conception, we see (Fig.19a.) that AE intensity is very great, one might say that it is of “explosive” character, and AE pulse appearance frequency in relation to the load applied is of stochastic character

At stage 4 (Fig.18) at which there is going on the microcrack growth, and, after its termination it is possible to suppose the transformation of microcrack into mesocrack, we see (Fig.19b) that AE intensity lowered in comparison with the stage №2, AE pulses appear in each loading cycle, but their value and frequency in relation to the load applied is of accidental enough character. At stage №6 (Fig.18), we see (Fig.19c) that AE pulse position and intensity in relation to the load applied have stabilized, which according to “Method of the evaluation of fatigue crack growth when cyclic-testing units”, is a sign of the turning of a micro (meso)crack into a macrocrack.

Conclusion

1. Conducted the modernization of AE АФ-15 instrument. АФ-15 instrument for data registration is connected to PC, there as well appeared a possibility of conducting synchronous recording AE parameters and those of the load applied.

2. Conducted investigation of the regularity of the rise of fatigue cracks and of obtaining the correspondence of the alpha criterion with the moment of fatigue crack rise.

By the results there were drawn the following conclusions:

- a break on the dependence of summary AE on loading cycle number («α» criterion) is identified as the moment of microscopic size fatigue crack conception.
- if at the initial testing stage on the dependence of summary acoustic emission on loading cycle number there are observed several breaks, several «α» angles, then the number of «α» angles corresponds to the number of fatigue cracks arisen.

3. Investigated the model of quantitative evaluation of fatigue crack growth speed by the summary AE in the loading cycle. Demonstrated that in crack conception stage it is necessary to take into consideration in the calculation only that summary AE in each loading cycle, which falls to the stage of summary AE accelerated growth on loading cycle number («α» criterion).

4. On the ground of AE method there was worked out “Method of the evaluation of a fatigue crack when cyclic-testing units", protected by patent №13853 of the Latvian Republic.

5. The results of the work have been introduced at the “Aviatest LNK» SIA enterprise in the form of a procedure “Procedure of AE control at test-bench fatigue testing of load-bearing units”

6. Conducted the approbation of fatigue crack growth evaluation method when cyclic-testing units when fatigue testing propeller pitch control arm of EH-101 helicopter . The results obtained confirmed the efficiency of the given method for the indication of the moment of the rise of a macrocrack.