UDC 620.179.1 DOI: 10.18372/0370-2197.1(82).13482

M. V. KARUSKEVICH, T. P. MASLAK, S. S. SALII, O. P. LYNNYK

National Aviation University, Ukraine

VARIABILITY OF THE FATIGUE INDICATOR SENSITIVITY AS A WAY TO ITS MULTIPLE FUNCTIONALITIES

The paper describes the possibility to adjust the sensitivity of a fatigue damage indicator with respect to the loads applied to the monitored components. It is shown that the optimum geometry of the indicator and its sensitivity can be achieved by the application of the finite elements stress-strain analysis. This extends application of the proposed indicator onto a large number of aircraft components even those carrying small loads and loaded by compression. This approach provides also the additional possibilities to use fatigue indicators for inspection of wide range of engineering structures.

Key words: *aircraft fatigue; fatigue indicator; finite element analyses; sensitivity of indicator*

Introduction

The concept of structurally sensitive fatigue indicator has been proposed as the result of few decades of researches conducted at the National Aviation University. The studies of the persistent slip bands and extrusion/intrusion on the surface of single crystals of aluminum [1] and on polycrystalline aluminum layer of clad constructional alloys [2; 3] under the different loads, static and repeated loads have been carried out.

As a result of mentioned researches it was concluded that the strong relationship between the intensity of the surface deformation relief, consisting of persistent slip bands, extrusions and intrusions and accumulated fatigue damage exists.

Appearance of the surface relief under the mechanical loading is not inherent property of all constructional metals and alloys, thus direct inspection of the surface and estimation of accumulated damage are not possible for wide number of materials. The decision of the problem has been found in the application of attachable indicators with required properties.

The paper describes the concept of the indicator able to react on operational loads on different components of the aircraft as well as for many other metallic constructions.

Basic design and phenomenological background

The concept of the fatigue indicator based on the monitoring of the surface relief was proposed and considered in the work [4]. Indicator is made of alclad aluminum alloy D16AT. The application of the well known alloy 2024T3 is also possible due to the similar composition and presence of the aluminum cladding layer. Chemical compositions and mechanical properties of the D16AT are shown in the table 1.

Table 1

Chemical composition of the aluminum D16AT alloy

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	90.7 - 94.7	Mg	1.2 - 1.8	Si	Max 0.5
Cr	Max 0.1	Mn	0.3 - 0.9	Ti	Max 0.15
Cu	3.8 - 4.9	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.5	Other, total	Max 0.15		

Both materials exhibit possibility to form surface deformation relief which correlates with accumulated damage. The aluminum layer of cladding reacts on the deformation by the appearance of the deformation relief.

Basic version of the fatigue indicator made of the D16AT alclad alloy sheet is shown in fig. 1. This conceptual version was installed on the fatigue test specimen and then tested under the loads close to the operational for the aircraft spar at the root section of the wing. The monotonic evolution of the deformation relief was observed and quantitatively described with estimation of the damage parameters according to the procedure proposed early [2, 3].

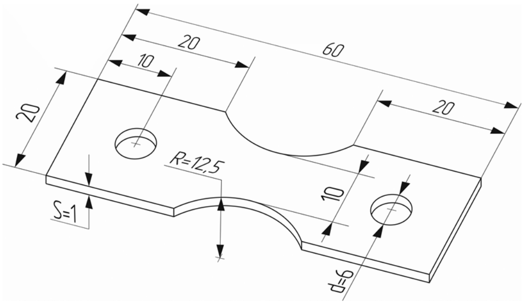


Fig. 1. Conceptual design of the fatigue indicator with local stress multiplication

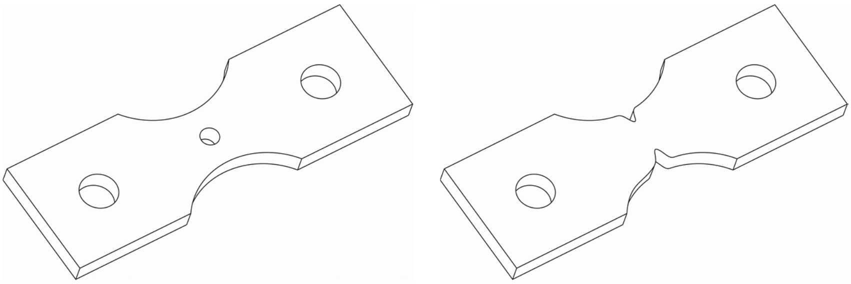
For the proposed and shown in fig.1 design of the indicator the local increase of the stresses and strains characterized by sensitivity factor *K*:

$$K = \frac{\varepsilon_{insp}}{\varepsilon_{comp}},$$

where ε_{insp} – strain at the indicator inspecting spot; ε_{comp} – strain of the component. Inspected area here is a narrowest section of the indicator.

By the variation of the geometry and corresponded factor *K* the required level of stresses at the inspection zone can be achieved to make indicator sensitive to the operational loads.

Additional way to improve sensitivity of indicator is the application of stress concentrators like: a hole at the working area of the indicator, and local notches as it seen in the fig. 2.



a) *b)*

Fig. 2. Indicator sensitivity increased by the hole at the center section (*a*); and by the notches (*b*)

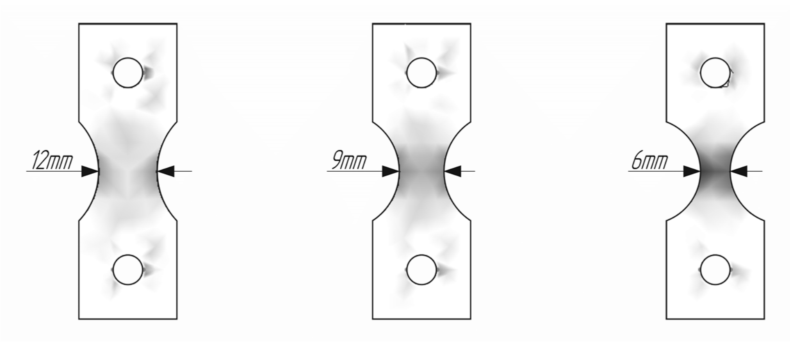
For the selection of the primary structure site for the indicator attachment, the general information about the aircraft wing loading in the flight and while moving on the airfield have been analyzed. For the planes, one of the most critical sites of the structure where the inspection is required is a root section of the wing spar. This is the more appropriate site for the indicator attachment. Thus, the constructional details, for example fasteners in the wing design influence dimensions and method of the indicator attachment.

Application of Finite Elements Tools for geometry optimization

Deformation relief is a result of dislocation process that actuates when the shear stresses in slip systems reach and exceed critical value. The condition for the slip process in the surface layer of the fatigue indicator is provided by the local stresses. The deformations of some aircraft components are enough for the slip actuating in the attached indicator whilst loads in some components are too small to actuate slip process after the limited number of cycles. Thus, fatigue indicators must be adopted for the particular stress-strain conditions. As it was shown above, the geometry of indicator determines the opportunities for the sensitivity increase. The practical usage of this idea is based on the application of the Finite Elements Method and correspondent stress-strain analysis.

Three indicators of different sensitivity are shown in fig.3. The maximum tension stress is equal 100.0 MPa. The indicator attached to the specimen for fatigue test made of the same alcald D16AT alloy.

Stress-strain analysis have been performed with the Dassault Systems Software that is a component of "SolidWorks 2016 Premium Edition". It includes "Simulation" pack, which allows simulation of the real-life loads, connections and fixations. The simulation performs in a few stages: creation of real-size computer model of the object that is under the analysis; specification of necessary material characteristics; definition of simulation conditions (such as loads, bracings and others, if it is necessary); computation and, finally, displaying of results in a user - accessible form such as graphs, animations and specific coefficients.



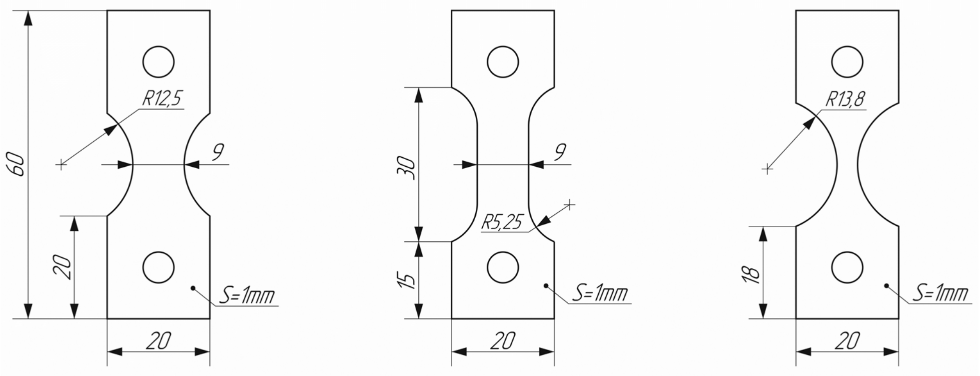
a *b* *c*

Fig. 3. Fatigue indicators with different sensitivity factor: *a* – 1,7; *b* – 2,1; *c* – 2,8

Redistribution of stresses and strains in the fatigue indicator provides local increase of the stresses in the area of surface inspection. The intensity of the grey colure indicates level of stresses in the inspected section of the indicator. While the stress in the specimen is equal to 100 MPa, the maximum stress in the first indicator is equal to 173 MPa, in the second indicator – 211 MPa; in the third indicator – 283 MPa. So, by this way the required sensitivity may be achieved.

At the same time another problem arises and requires decision. It is probability of the stability loss under compression. It is known, for example, that same components of the aircraft wing spar may be subjected to the tension or compression depending on whether the plane in air or on the ground. The application of the Finite Elements

Method has allowed us to solve the problem related to the loss of stability due to the incorrect geometry (fig. 4).



a *b* *c*

Fig. 4. Finite Elements Assessment of critical stresses for different geometry of the fatigue indicator: *a*) σ=13,5 MPa; *b*) σ=10 MPa; *c*) σ=12,3 MPa

It is important that the critical stresses for all considered geometries are bigger than actual compression stresses in the investigated components, i.e. in the cap of spar, so there is no risk of the stability loss. Nevertheless, the procedure of the indicator geometry optimization needs stress-strain analysis both for tension and compression.

Conclusions

The list of objects where fatigue indicators maybe used can be extended by the optimization of the indicators sensitivity.

Required sensitivity of indicators can be achieved by the selection of the indicator geometry to reach determined value of sensitivity factor.

The Finite Elements Method is a reliable tool for the fatigue indicators geometry optimization.

Both tension and compression conditions must be considered while selecting the shape of indicators.

References

1. Zasimchuk E.E. Single-crystal as an indicator of fatigue damage / E.E.Zasimchuk, M.V. Karuskevich, A.I. Radchenko // Fatigue Fract. Engng. Mater. Struct. – Vol.15. – 1993. – № 12. – P. 1281-1283.

2. Extrusion/intrusion structures as quantitative indicators of accumulated fatigue damage. Karuskevich M.; Karuskevich O.; Maslak T.; Schepak S. International Journal of Fatigue, ISSN: 0142-1123, Volume: 39, Date: 2012-06-01, Pages: 116-121.

3. Application of Fractal Geometry to the Problems of Prediction of the Residual Service Life of Aircraft Structures. Karuskevych M.V.; Zhuravel' I.M.; Maslak T.P. Materials Science - New York, ISSN: 1068-820X, Volume: 47, Issue: 5, Date: 2012-05-01, Pages: 621-626.

4. Karuskevich M. Fatigue life prediction by the structurally sensitive damage indicator, "Proceedings of the National Aviation University". – 2012. – №1. – P.139–143.

The paper was received by the editorial office on the 22.02.2019.

М. В. КАРУСКЕВИЧ, Т. П. МАСЛАК, С. С. САЛІЙ, О. П. ЛИННИК

ЗМІНА ЧУТЛИВОСТІ ІНДИКАТОРА ВТОМИ ЯК ЗАСІБ ЗАБЕЗПЕЧЕННЯ ЙОГО БАГАТОФУНКЦІОНАЛЬНОСТІ

В статті показана можливість зміни чутливості індикаторів втоми відповідно до умов навантажування об'єктів, втомне пошкодження яких контролюється.

Розробка індикаторів втоми є результатом багаторічних досліджень втомного пошкодження монокристалічного алюмінію та полікристалічних алюмінієвих сплавів, що проводяться в Національному авіаційному університеті. В основі досліджень є процес формуванням деформаційного рельєфу на поверхні алюмінієвого сплаву Д16АТ під дією циклічних навантажень, а також тісна кореляція між інтенсивністю рельєфу та режимами навантаження.

В статті представлена концепція індикатора втоми, що може реагувати на експлуатаційні навантаження різних конструктивних елементів літака так само як і на навантаження інших металевих конструкцій.

Чутливість індикаторів втоми суттєво залежить від перерозподілу напружень в перерізах індикатору. Запропоновано кількісну характеристику – коефіцієнт чутливості.

Зміною геометрії індикаторів можна досягти чутливості, необхідної для реагування стану поверхні індикатору на зовнішнє механічне навантажування. Оптимізація геометрії індикаторів досягається застосуванням методу скінченних елементів.

Важливим результатом роботи є також перевірка працездатності індикатора при дії стискаючих напружень. Показано, що в діапазоні визначених напружень стискання розглянута геометрія індикаторів не призводить до втрати стійкості. Таким чином, показана можливість застосування запропонованих індикаторів втоми для оцінки накопиченого втомного пошкодження елементів конструкцій літака, які працюють в умовах розтягу та стиску.

***Ключові слова*:** втома літаків; індикатор втоми; метод скінченних елементів; чутливість індикатору.

Карускевич Михайло Віталійович – д-р техн. наук, професор, професор кафедри конструкції літальних апаратів Навчально-наукового аерокосмічного інституту Національного авіаційного університету.

Маслак Тетяна Петрівна – канд. техн. наук, доцент, доцент кафедри конструкції літальних апаратів Навчально-наукового аерокосмічного інституту Національного авіаційного університету, maslakt@yahoo.com.

Салій Сергій Сергійович – студент Національного авіаційного університету.

Линник Олександр Петрович – аспірант кафедри конструкції літальних апаратів Національного авіаційного університету.