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Current state of the R&D on indicator for biaxial fatigue monitoring

Current state of the research and development headed to the development of the family of sensors for fatigue monitoring of aircraft parts subjected to uniaxial and biaxial cyclical loading is described. Phenomenological basis for the fatigue sensor is described. Examples of the sensor's designs are shown as physical and digital models. Areas of the fatigue sensors application are outlined.

Fatigue damage monitoring problem

Metal fatigue is one of the main factors limiting lifespan of machines and mechanisms, in some cases leading to the catastrophic failure. One of the inherent features of the process of fatigue damage accumulation is its stochastic nature, which manifests itself at the stages of fatigue crack formation and propagation. The reason of fatigue life scatter is the diversity and large number of factors influencing the process of damage: material properties, design features, the presence of stress concentrators, the level of operating loads, the order of loads action, etc.

Irregularity of loading is a factor that cannot be avoided due to the real operational conditions and external and internal loads.

Aircraft structure is subjected to the action of aerodynamic loads, inertia, excessive pressure in the cabin, motor vibration, oscillations caused by the aerodrome unevenness and so on. These loads have different frequency and amplitude, at the same time almost all cyclically repeated loads contribute into fatigue damage of metal structural elements. The simultaneous action of these loads makes the fatigue process almost unpredictable.

The basis for the fatigue life calculation of structural elements loaded irregularity is the rule of linear summation of fatigue damage proposed first by the Palmgren [1] and then developed for practical needs by Miner [2].

Despite the absence of phenomenological substantiation of the Palmgren-Mainer' rule as well as observed deviation from the expected prediction, this rule still widely used in different areas including aviation due to its simplicity and possibility to get at least preliminary forecast.

To increase the accuracy of the fatigue life prediction in addition to analytical methods, nowadays the numbers of researches and developments have been carried out in the field of the development the instrumental tools for fatigue damage assessment. This methods belong to the nondestructive diagnostic of metal, conducted by: a) direct diagnostic of structural material; b) assessment of the accumulated fatigue damage of fatigue sensors (aka fatigue indicators, fatigue gauges, specimen-witnesses, etc.), which are being attached to structural elements are involved into the work of structural element under operational spectrum of loads and change their state according to the loading history. Early proposed sensors are based on the possibility to measure change of electrical resistance, length of the crack, intensity of the light reflection, etc. [4, 5]. Apparently, the application of sensors is preferable way to monitor fatigue damage because of the big number of metal properties evolving under the loading, and possibility to control the sensitivity of sensors according to the conditions of their work.

The contribution into the field of fatigue sensors development has been made at National Aviation University by the introduction of concept of multifunctional Structurally Sensitive Indicators [6]. It is obvious that variety of machines, mechanisms and their loading conditions encourages the efforts for development of the family of fatigue sensors.

Aim of the research and development

Taking into account drawbacks of the analytical methods for quantitative assessment of accumulated fatigue damage, the family of the fatigue sensors for wide range of loading modes is being under development. New research and development is based on the successful development of the uniaxial fatigue sensor of the first generation, new experimental data on multiaxial fatigue and possibilities of the 3D design and Finite Elements Analysis.

Uniaxial and biaxial fatigue sensors

The first surface relief indicator was made of a 20mm x 10mm x 0.2mm single-crystal aluminum foil (99.99% Al) [7]. Being attached to the structural element (specimen) sensor reacts to the loading by appearance of slip lines on the surface, thus the density of slip lines was considered as an indicator of accumulated fatigue damage. Accuracy of the fatigue damage was improved by application of fractal analysis [8].

Polycrystalline Surface Relief Fatigue Indicator (PSRF) looks like a miniature specimen of aluminum alloy 2024T3 for fatigue test with stress concentrator for localization of the damage accumulation and precise determination of the check spot. As a result of the cyclical loading the extrusion/intrusion structure appears and intensifies in the fatigue process, thus making it is possible to assess fatigue damage by the methods of light microscopy [9, 10].

One of the current versions of the uniaxial fatigue indicator is shown in Fig. 1.

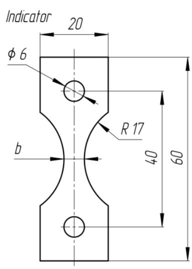

Fig. 1. Uniaxial fatigue indicator

As proved both by the conventional calculating methods and by the Finite Elements Analysis, the geometry of the indicators influences local stresses in the mid-sections of the indicators. Thus, the possibility of the indicator's sensitivity variation exists.

It is proposed now to use the same principle for fatigue monitoring at biaxial loading. In the process of the search for the optimum geometry for the biaxial indicator, its shape evolved from the shape of the typical cruciform specimen [11] to the sensor's design with the required sensitivity and localization of inspected spot.

In the latest variant of the sensor the effect of the local increase of the stresses for improvement of the indicator sensitivity has been achieved by two factors: a) by narrowed arms, b) by cone reduction of the indicator thickness at the center area (Fig. 2).

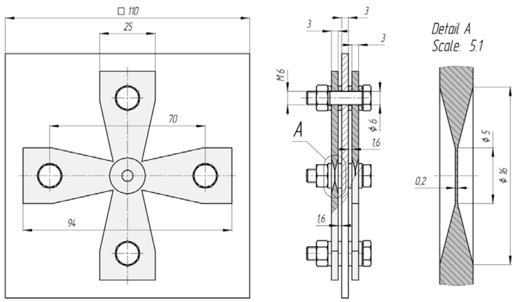

Fig. 2. Dimensions of accepted conceptual design (unit: mm)

As a result of the geometry optimization, the new Indicator design has got the following features: the arms of the indicator's cross are narrowed from the attachment points to the center; the center section in the area is limited by the circle having reduced thickness from 3.0 mm to 0.2 mm. There is a flat surface at the center with a radius of 5 mm. The thickness of the flat center area is 0.2 mm.

The clad layer is absent as the indicator's center spot, so there is no possibility for surface relief formation. Two options are possible:

- attachment of the aluminum single crystal foil sensitive element;
- attachment of the polycrystalline aluminum foil sensitive element.

Both materials are sensitive to cyclical loading and demonstrate surface deformation relief (extrusion/intrusion structure). Dimensions of the sensitive element are 5 mm diameter; 0.15 mm thickness. The cyanoacrylate glue provides attachment, widely used in the aviation industry for strain gauge attachment at fatigue tests or aircraft flight tests.

Aircraft structure withstands different combination of loads: pressurization of the cabin, bending and twist of the fuselage due to the control surface deflection, loads transmitted from aircraft parts; hence the demand for fatigue monitoring can be met by the diversity of the sensor's geometry and correspondent sensitivity.

Conclusions

Fatigue monitoring and assessment of the consumed life span of aircraft and many others metal engineering structures can be performed by the application of fatigue sensors, based on the possibility to monitor surface deformation relief.

Fatigue sensors can be used both for the uniaxial and multiaxial fatigue monitoring. Design and application of sensor for uniaxial fatigue monitoring to the moment is completely substantiated and ready for practical application. Due to the indefinite number of stress components combination for multiaxial loading of engineering structures, the interpretation of surface relief at the multiaxial loading requires additional experimental data.

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