Probability Characteristics of Strain Gauges of Fatigue Damage

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The evaluation of damage, taking into account the scattering characteristics of the damage gauges indications, is essential.

A method of damage evaluation under low-cycle structure loading, based on the account of the strain gauges indications scattering, is proposed. The variance of gauges indications in the process of low-cycle loading and the variance of their life is taken into account.

The criterion equation determining the structures and damage gauges life is taken as a deformation-kinetic criterion.

In the probability approach on the example of a pressure vessel, was made an evaluation of the structure with the use of strain gauges of fatigue damage.
A typical response to the accumulation of fatigue damage in metals are changes of their electrical properties under cyclic strain condition. The connection between the two processes is of interest from the point of view of eventual utilization for the evaluation of the fatigue damage of constructions operating in the low-cycle condition.

However, the direct measurement of the electrical parameter characterizing the degree of damage of the construction under control is practically impossible. The installation of special gages in the dangerous local zones has turned out to be much easier. It is possible to control the fatigue damage process in the construction by considering the changes of the electrical resistance.

At present in several fields of engineering, in aircraft engineering, for example, the so-called "damage gages" for the continuous control of the exhaustion of the service life of the most important elements of lifting constructions are used /1,3/.

These gages utilization is possible if the calibration on the similar construction operating under control enables a direct dependence between the electrical change of the gage resistance and the run-out part of the construction service life to be determined. In this case the gages geometrical characteristics are not so important, their installation in the zones with stress concentrations, where an intensive accumulation of fatigue damage occurs, is not necessary. Any resistors responding to cyclic strain unambiguously can be used as gages.

The above-mentioned approach caused the advent of polymer damage gages /4/ with graphite particles as a base forming a continuous random grid of electroconductive chains in the epoxy matrix. The resistance of the electroconductive chains grid in the process of cyclic strains decreases due to the contact increase between the graphite particles as a result of their gradual overlapping. The intensity of the process has a functional connection with the strain amplitude, it enables polymer conductors as damage gages to be basically used; though, their time and temperature instabilities set a great limit on their potentialities.

Still other metal strain damage gages with a certain dependence of \( \Delta R / R \) on \( N \) under different cyclic strain amplitudes are offered.

On the whole, only small-base strain gages made of annealed constantan foil (which Harting has suggested using as a material for a damage range) appear to be suitable under service conditions out of all meters available. It occurs when it is necessary to install a damage gage in a real construction, or sometimes in a unique one where recalibration is impossible.

In real constructions the fatigue damage process starts, as a rule, in the stress concentration zones which are sometimes very small in extent. Damage gages operate with positive action only if they are installed in these zones of the construction under control. Therefore, it is
necessary to have gages capable of measuring strain on a small base. Besides, not only the main strain component \( \varepsilon_1 \), is responsible for fatigue damage, but \( \varepsilon_2 \), as well. Then, it is necessary to have a gage responding to both components. In this case, its installation must take place right in the direction of the main strains. If the direction of the main strains is not known, it must be first brought out by means of a sensitive coating or multi-component sheaf of strain gages.

Taking into account the above-mentioned considerations and the readouts of constantan strain gages under cyclic loading / 5,6 /, as well as the results of verification of their operation as damage gages / 7 /, universal small-base foil strain gages in the form of chains of two-component orthogonal sheaves with an anchor closing of the tennometric grid improving the strain transmission from an item to the strain gage were worked out. A small base (0.5 mm) and a tight arrangement in the chain makes it possible

1) to have a clear picture of strain distribution in the zone under study and then to determine the coordinates of the places of maximum strain, i.e. zones of maximum fatigue damage;

2) to get the exact value of the strain material intensity amplitude \( \varepsilon_i = \int (\varepsilon_1, \varepsilon_2) \) in these zones and after already the first loading cycles to make a forecast of the fatigue life of the construction under control according to the known formulas connecting the strain intensity range \( \varepsilon_i \) with the number of cycles before the damage \( N \) (within the bounds of the strain criterion of the fatigue damage);

3) to obtain the necessary information from the sheaf of two orthogonal strain gages placed in the zone with maximum strain now as a fatigue damage gage. To perform this, one should connect these strain gages in series (Fig. 1) and to connect them to the apparatus as an integral damage gage. The gage will fix both strain components \( \varepsilon_i \) and \( \varepsilon_2 \) summing up their influence on the alternation process of a relative electrical resistance \( \Delta R/R \).

The corresponding data are given in figures 2 and 3 as an example of operation with the universal strain gages suggested. Testing of the potentialities of the gages under consideration was made on a fragment of a real sheet construction with a typical concentrator in the zone of contact between the cylinder pipe and the spherical shell. The gages show the zones where the strain is a maximum with great precision and make it possible to select the necessary sheaf to reinstall it into a two-component damage gage.

The forecast based on the results of the strain range measurements was a success after several loading cycles (Fig. 3). The fatigue damage accumulation process up to the damage point was registered. It became possible as the strain gages fatigue strength in the particular case has turned out to be higher than that of the controlled units. The strain gages fatigue curves were determined in the process of their study under various statio-
nary loading conditions with different values of a mean strain. Their behavior under non-stationary loading conditions was studied, the process of unilateral strain accumulation being simulated /7/. The corresponding data are shown in figure 4. Probability characteristics of the strain gages suggested are presented in figures 5 and 6.

To finish with, it should be noted that for the sake of a further development of the methods of evaluation of a construction fatigue damage, it is necessary to get answers to many questions arising in the process of work. The influence of cyclic frequency, the environment temperature and other factors on the gages characteristics must be examined. Questions connected with the apparatus, as well as some other problems need their solution.

The optimum variant of the damage gage utilization is sure to be the one when the gage fatigue and the construction under control curves coincide, or are close. From this point of view, one should look for technological and other factors affecting the strain gages fatigue characteristics, to learn how to vary them and to approach the optimum variant to control a fatigue damage process of any construction made of any material.
References

/1/ СЕРБЕЗНОВ А.Н. Измерения при испытаниях авиационных конструкций на прочность. М., Машиностроение, 1976, с. 224.


Figure 1. Chain of two-component strain gages sheaves on the shell with a variable ratio $d'_1 / d'_2 = \varepsilon'_1 / \varepsilon'_2 - 1$.

![Figure 1](image)

Figure 2. Strain distribution in the zone of interface of the shell with the pipe in the process of hydrocompacting (a-outer surface, b- inner surface).

![Figure 2](image)

Figure 3. The results of fatigue tests of strain gages ($-\sigma - \varepsilon_{\text{mod}} = 0$; $-\sigma - \varepsilon_{\text{mod}} = 1, 2, 3, 4$) and constructive elements ($-\sigma - \text{Al-alloy shells}$; $-\sigma - \text{Al-Mg-alloy shells}$). Curves 1 and 2 forecast.

![Figure 3](image)
Figure 4. Measurement data for non-stationary cyclic loading.
1 - experimental data, 2 - calculations, 3 - loading condition.

Figure 5. Distribution of cycling strain readings at non-stationary cycling loading (in percent):
1 - $E^{(10)} = 0.48$; 2 - $E^{(100)} = 0.56$; 3 - $E^{(1000)} = 0.66$;
4 - $E^{(10)} = 0.75$; 5 - $E^{(100)} = 0.9$; 6 - $E^{(+10)} = 1.0$.

Figure 6. Values of mean ($\bar{E}$), standard deviation ($\delta$) and variation coefficient ($\nu$) of tensometric readings as a function of strain range at non-stationary cyclic loading.