Studying optoelectronic detectors for fatigue parameters control on machine-building metal surfaces

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Abstract. The article introduces methods and experimental findings of semiconducting optron characteristics in the optical fiber systems with open channels to determine fatigue of metal constructions. This device consists of a detector element and an electronic unit.

1. Introduction

Material fatigue (in particular, metals) is decay due to repeated stress. Materials ability to resist stress during fluctuating loads is called materials fatigue resistance [1].

Fatigue failure happens at one of the following peculiarities of loading:

1) during repetitive loading of the similar sign, for example, alternating from zero to maximum;
2) during repetitive loads, alternating in intensity and in sign (sign-alternating loads), when the material strength is simultaneously impacted by repeated and variable load. Here symmetrical and asymmetrical loadings are distinguished.

For fatigue failure alternating loads are not enough. Loads should be of a certain magnitude. Maximal load when material resists without failure at any arbitrary large number of load repetition is called fatigue limit.

Fatigue fracture of metal has a characteristic view. It usually has two zones: one (A) is smooth, ground, due to evolution of the crack; the other (B) is coarse-grained, appeared at the final break of the weakened by the fatigue crack of the part cross-section. Zone B in brittle materials is coarse-grained and in viscous materials is fibrous [1–3].

Cracking mechanism at repeated-alternating loads is complex and cannot be considered as thoroughly studied. As absolute statements of fatigue theory the following can be mentioned:

1) processes happening in materials at repeated-alternating loading are localized;
2) tangential stress has dominant influence on fatigue phenomenon till first crack formation. They cause flow shears and shear destruction. Fatigue crack growth fastens if tensile stress is present and in ductile, especially brittle materials (for example, cast iron) where a third of breaks appearing increase sensitivity to tensile stresses. Fatigue limit is determined experimentally with corresponding test machines by testing not less than 6–12 samples made from this material. Fatigue limit depends on many factors, form and size of the sample or detail, treatment, surface condition, stress pattern (strain – pressure, torsion, bending), law of load variation in time during test, temperature and so on.
2. Materials and methods
Fatigue nowadays is one of the main reasons for machine parts and construction elements failure which are under stress alternating in time. In connection with this material choice, mode and production technology grounding for half-products and details manufacture, technical process control, providing constant and high resistance of construction elements to fatigue failure are important for increasing durability of constructions.

To increase machine durability and reliability conditions probabilistic methods for stress calculation at alternating loads are elaborated and implemented with the account of random character of the acting loads, and materials and parts fatigue characteristics variation [4, 5].

Fatigue resistance of materials and parts is determined by fatigue tests of samples, models, details and constructions in general, which require high costs and long time, which a design-engineer is deprived of at the design stage and structure refinement. In connection with this scientists from different countries search for calculating methods (indirect) methods to estimate fatigue resistance and methods of accelerated and rapid fatigue testing.

3. Results and discussions
Total of successive stress values for one period of their change at regular loads (figure 1) is called stress cycle.

Stress cycle characteristics are:
- Cycle time $T$ is duration of one stress cycle, $T = 1/f$ (figure 1).
- Maximum stress per cycle $\sigma_{\text{max}} (\tau_{\text{max}})$ is the greatest cycle stress by algebraic value (figure 1, figure 2).
- Minimal stress cycle $\sigma_{\text{min}} (\tau_{\text{min}})$ is the minimal cycle stress by algebraic value (figure 1, 2).
- Average cycle stress $\sigma_m (\tau_m)$ is a constant (positive or negative) element of the stress cycle (figure 1, 2), equal to algebraic half-sum of maximal and minimal stress cycle:

$$
\sigma_m = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}, \quad \tau_m = \frac{\tau_{\text{max}} + \tau_{\text{min}}}{2}.
$$

![Figure 1. Stress cycles.](image)
Figure 2. Stress cycles parameters in the area of stretching and compression.

Stress cycle amplitude $\sigma_a (\tau_a)$ is the greatest numerical positive value of the stress cycle variable component (figure 1, figure 2) equal to algebraic half-difference between maximal and minimal stress cycle

$$\sigma_a = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}; \quad \tau_a = \frac{\tau_{\text{max}} - \tau_{\text{min}}}{2}.$$  

Stress ratio $R_\sigma (R_\tau)$; relation of minimal stress cycle to maximal:

$$R_\sigma = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}}; \quad R_\tau = \frac{\tau_{\text{min}}}{\tau_{\text{max}}}.$$  

Fatigue nowadays is one of the main reasons for machine parts and construction elements failure which are under stress alternating in time. In connection with this material choice, mode and production technology grounding for half-products and details manufacture, technical process control, providing constant and high resistance of construction elements to fatigue failure are important for increasing durability of constructions.

For example main principles of determining fatigue and fatigue life are given in work [5]. Fatigue life is number of stress cycles or deformation of a certain nature which a sample can stand before failure.

Life-time of many metal constructions is determined by fatigue resistance of the constructive elements. Fatigue endurance of the construction elements depends on many factors.

Life-time also depends on production technology, materials and half-product quality, details, component parts and aggregates, peculiarities of craft utilization, completeness and periodicity of regulation and maintenance operations, engineering service and inspections etc. Consequently, providing life-time characteristics of the aircraft is a complex problem, which is solved by different methods at the stage of design and utilization.

This work studies influence of different technological factors on life-time characteristics of a typical craft elements. Residual stress formation in the area stress concentrators has been studied. Methods for fatigue endurance increase based on creation of favorable residual stresses have been estimated.

Solution of these problems provides practical possibility of grounding by fatigue endurance increase of construction elements with technological methods.

Influence coefficients have been determined by the findings for qualitative estimation of influence of some constructive-technological factors on static strength characteristics and fatigue durability of samples.

Systematizing and unifying the results of stress and fatigue tests of samples, manufactured by different technological processes, there appeared a possibility basing on CALS-technologies to create
data bank on influencing constructive-technological factors on static strength and fatigue endurance of the constructive elements.

Data bank has been created of technological heredity influence on life characteristics. This bank includes material mechanical characteristics and material and construction elements life characteristics, done by prospective and traditional technologies with the account of modeling operational conditions.

Machine parts fatigue is greatly determined by construction, technological, operational and other factors, which are difficult to take into account calculating fatigue endurance of mechanical constructions. In connection with this, fatigue tests of materials and real details in operational conditions at the stage of refining the final variant of the construction are a decisive element in the process of creating reliable and durable machines.

But these tests are rather complicated as fatigue cracks appear on details in hard-to-reach places filled with different substances. That is why it is necessary to create built-in-test equipment allowing keeping track of crack development on details in operational conditions with the account of their operation and test modes.

Nowadays some optoelectronic devices for non-destructive examination of substances and materials have been developed [6-7].

Figure 3 shows the structural scheme of an optoelectronic system, and figure 4 shows one of the detector options.

![Figure 3](image)

**Figure 3.** Structural scheme of optoelectronic system for fatigue control of metal constructions.
Optoelectronic system includes a branched structure with six independent alike branches (chains). Every chain controls a certain parameter of the metal construction, for example, the first, the second, the third control chroma, the forth controls surface roughness, the fifth controls graininess and the sixth for defects presence.

Detector is in the form of semitubal base or hollow semi-cylinder 1, where three couples of Y-like and 2 – 4 or three common 5 – 7 lead-in fiber optics, six off-takes 8 – 13 fiber optics, and three supporting fiber optics 56 – 58 compose an electronic module.

The electronic module includes an audio-frequency generator 15, a commutator 16, six bistable latches 17 - 22, whose six outlets are connected with six measuring light emitting diodes (LED) 23, 25, 27, 29, 31, 33 second six outlets with compensating LEDs 24, 26, 28, 30, 32, 34. All measuring LEDs are linked with conducting fiber optics 2 – 7 with CO (controlled object) 14, and compensation LEDs are connected differently. For example, LED 24, 26 and 28 are connected via CO to corresponding optical receivers (OR) and compensation LED 30, 32 and 34 are connected with corresponding ORs 38, 39 and 40 optical supporting fibers 56, 57 and 58 leaving out CO 14. Outlets of every of six ORs 35 - 40 are connected to the inlet of the corresponding comparison module 41 - 46, outlet of everyone of them is connected with corresponding measuring device 47 - 52. Then the electronic module includes a visual signal processor unit (VSPU) 53, 3Y 54 and a measuring system, for example, ECM - 55.

The device works so: the audio-frequency generator 15 produces rectangular pulses which are fed onto inlet of the commutator 16. Separated impulses are further fed onto inlet of six identical distable latches 17-22, whose six outlets are connected with six measuring LEDs 23, 25, 27, 29, 31, 33, another three outlets are connected with compensatory LEDs 24, 26, 28, 30, 32, 34, impulses from distable latches go to corresponding LEDs.

CO 14 is incased in the semitubal base or hollow semi-cylinder 1, with lead-in Y-like 2 - 4 and three common 5 – 7 fiber optics is exposed to two light fluxes measuring and compensatory ones. Fiber optics are incased in semitubal housing of soft gum for necessary detector movement and light blocking of optical channel, they are placed at the angle of 45° relative normal to CO in the refractory point during chroma control, and at the angle ≈ 30° during surface roughness control and others. [8–10].

During chroma control optical radiation is reflected from CO 14 and by output optical fiber 8 - 10 is led to ORs 35-37 which modify optical signals into electric ones. These ORs operate on wave length λ1=680 nm, λ2=560 nm and λ3 =450 nm.

Thanks to light transmission through lead-in 2-4 and led-out 8-10 fiber optics narrow-beam radiation is emitted and accepted which allows controlling chroma [9-10].

4. Conclusion
This device substitutes visual inspection of technological parameters of the tested surface according to GOST 9378-93 compared to etalon samples, calculations prove the device cost to be several times lower than that of foreign analogues. Objectivity, efficiency and control precision of this device are much higher than those ones of visual inspection. Such a device can be built in automated machinery for
simultaneous control of several technological parameters of metal surfaces such as roughness, graininess, chroma and presence of defects.

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