Research of microdeformation and stress in details of agricultural machines by implementing holography

I L Rogovskii[1], I M Sivak[1], S A Voinash[2,6], V A Sokolova[3], T G Garbuzova[3], A A Rzhavtsev[3], G E Kokieva[4] and N N Romanyuk[5]

[1]National University of Life and Environmental Sciences of Ukraine, 15, Heroiv Oborony str., Kyiv, 03041, Ukraine
[2]Novosibirsk State Agrarian University, 160 Dobrolyubova str., Novosibirsk, 630039, Russian Federation
[3]St. Petersburg State Forestry University named after S.M. Kirov, 5 Institutskiy Per., Saint-Petersburg 194021, Russian Federation
[4]Arctic State Agrotechnological University, 3, Sergelyakhskoye shosse 3 km, Yakutsk, 677007, Russian Federation
[5]Belarusian State Agrarian Technical University, 99/1, Nezavisimosti av, 220023, Minsk, Republic of Belarus

[6]E-mail: sergey_voi@mail.ru

Abstract. The article presents theoretical and experimental studies of microstrains and stresses in the details of agricultural machines by the implementation of holography.The expansion of computer holography, associated with the development of optical methods for studying the technical condition of agricultural machinery and their components, is accompanied by significant complications associated with the interpretation of interferograms. An important solution was to investigate the process and the associated appearance of microdeformation fields on the surface of the product without destroying it. In this case, the conditions of the allowable load and, accordingly, the allowable technical condition of the product were created, when the natural sample or the real part was not destroyed, and the hologram was recorded at the time of appearance and development of microdeformations. The hologram reproduced the kinetics of the process in a three-dimensional image, where all the elements of the study were in real time and real size, which made it possible to capture the three components of the microdeformation vector. Such experimental researches for establishment of admissible values of a technical condition were carried out according to the developed technique were carried out for the first time. The use of holography as a means of research allowed to obtain the values of microdeformation in three directions of the vector, as well as to mathematically describe the dependence of these deformations on the coordinates.

1. Introduction

During operation, agricultural machinery is exposed to various external and internal loads [1], which cause intense wear of working surfaces [2], material fatigue [3], and damage to contact surfaces [4]. The situation becomes especially dangerous when the power load is accompanied by the combined action of elevated temperatures [5], an asymmetric loading cycle [6] and a change in the lubrication regime [7]. In most cases [8], the destruction of parts begins from the surface layers and is determined by their resistance to wear [9], as well as the magnitude of the contact load in the working areas [10].All existing measures to improve the reliability of agricultural machines are ineffective and imperfect if quality control of the manufacture and repair of products is not properly organized [11].

The presence of surface and hidden defects in parts, damages that manifest themselves in the form of internal metal delamination [12], intercrystalline and external cracks, curvature of crystal lattices, non-metallic inclusions, pores and fistulas, which leads to a loss of machine performance [13].Untimely replacement of such products with defective surfaces will certainly lead to the appearance of a conditionally serviceable machine in operation [14].The probability of failure of such machines is 50% and depends on the time when [15], under favourable conditions, an undetected defect or damage will destroy the part and disable the machine [16].An acute problem is the rational use of domestic materials [17], the production of which is being established by agricultural engineering enterprises [18].Improper use of materials without scientific justification and preliminary calculations for strength [19] and fatigue causes premature failures, loss of performance and low reliability of equipment [20].

Especially important is the task: to assess the residual life of the product, to determine the values of the parameters of its permissible or limiting states, to establish the value of internal and residual stresses [21], to find and register changes in the technical state of the product under the influence of the established loads [22]. This creates conditions for studying the stress state of parts [23], establishing the location and magnitude of stress concentrators [24], and thereby predicting the residual life of machines.

The study of the stress state of the working surfaces of parts is based on those developed by scientists from the Munich Center for Applied Optics (Germany), Ghent University (Belgium) with the direct participation of the authors. Analysis of the literature has shown that the study of the processes passing with the destruction of surfaces of the limiting state must be carried out in a complex combination of two types of optical interferometry [25]. This is due to the special possibilities of using each of the marked types of control for a specific type of research [26]. Computer holography makes it possible to register changes in the surface at low, not limiting loads, which pass at low rates of change in the state of the surface [27]. The image of a deformed body, represented in the form of colored interference fields, is recorded in the computer memory [28]. In the second case of holography, the object is captured in three-dimensional imaged on a film or glass photographic plate along with interference lines. It is used to study high-speed dynamic processes, sometimes associated with the destruction of the surface or the entire part [29]. The principle of operation of each type of holography is based on the double exposure method, when the body is observed before and after the application of the load. At the same time, changes in the state of the surface of the part are measured by comparing each of its sections with its changed state [30]. A defect or damage to a part manifests itself in a local anomalous placement of interference fringes. In the case of computer holography, these are colored stripes (each color corresponds to a certain amount of deformation), in another case, these are black and white stripes.

2. Purpose of research

The purpose of the research is to establish the feasibility of using holographic methods to determine the parameters of the technical condition of the working surfaces of parts, assemblies, aggregates and agricultural machines, to identify hidden defects, damages, to study the stress-strain state and related possibilities to increase the reliability of agricultural machines.

3. Materials and methods

To conduct research, low-pressure polyethylene was used as a sample material (representative of a wide range of agricultural machinery parts), for example pipes: diameter 120 mm, wall thickness 10 mm, pressure of the working area 0.3-0.4 MPa, product temperature at the moment the experiment was 0°C. Cooled air was pumped into the initiation zone. The destruction was initiated by a scat pendulum. To trigger the laser, a Triger-system block device was used, the diagram of which is shown in figure 1.

Moreover, a switch was installed at a distance of 100 mm from the initiation zone, which was connected immediately before the start of the experiment to the Triger-system unit. The switch is a silver wire stretched between two electrodes in the zone of predictable destruction of the part. With the destruction of the part and the development of a crack along it at a speed of 500-560 m/s, the wire was broken and the retarder in the device block was set to a certain delay time. Then the laser was switched on and double fixation of the destroyed part was carried out. The interval between two laser flashes was constant at 20 ns.

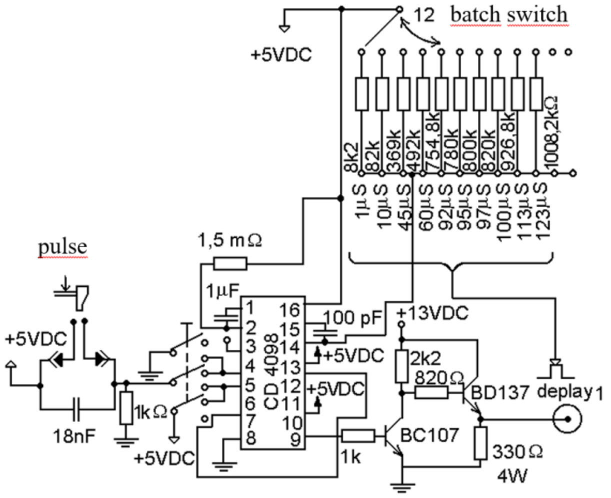

Figure 1. The scheme of the device for launching the laser at set intervals Triger-system.

During the experiment, two wave fields were recorded sequentially in the same hologram by the method of two exposures or frozen stripes. A pulsed ruby laser HLS-2 with a wavelength of 694 μm was used, and holograms were recorded on an AGFA film sensitive to red light.Examples of loading of parts are shown in figure 2. The laser was switched on not at randomly chosen times, but at precisely defined for each batch of investigated objects. The loads were carried out discretely, setting the weights of 50, 100, 200 for metal products and 5, 10, 20 N for non-metal ones, sequentially and repeatedly repeating the load until a clear interference pattern appears.

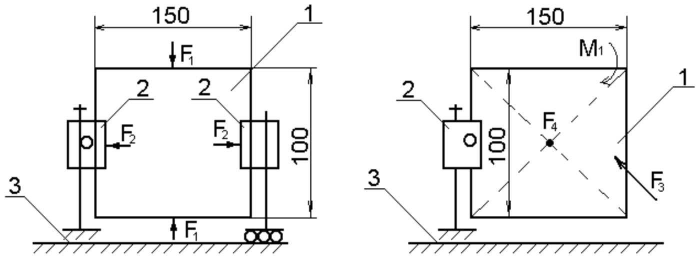

Figure 2. Sample load diagram F_1 compression, F_2 tension, F_3 bending, M_1 torsion, F_4 thermal, 1 sample, 2 clamp bracket, 3 desktop.

4. Results and discussion

Table 1 given ranges of loads, at which the process of appearance of interference fringes occurs, depending on the adjustment of the optical system and the capabilities of computer support. The given load ranges cover the load range.

Table 1. Mechanical load when examining real parts.

Part name, material	Mechanical load type			
	F_1(N)	F_2 (N)	F_3 (N)	M_1 (N m)

Internal combustion engine cylinder block, cast iron	400-500	-	-	40-60
Internal combustion engine piston pin, steel	-	800-900	750-900	80-100
Piston, aluminum	850-1100	500-620	-	-
Milk tap, steel	780-900	-	600-680	40-60
Cover, polyamide	150-200	-	18-22	-
Adapter connector, carbon fiber	30-34	25-27	18-20	-
Reducing sleeve, metal polymer	65-70	-	45-52	-

The calculation results were checked experimentally, which made it possible to refine the parameters of the holographic mode. As a disadvantage of the above methods, it should be noted that the experiments are carried out at clearly fixed discrete times. This does not make it possible to study the integral picture of the change in the microdeformation field of the product surface in time when the magnitude or nature of the load changes.

Disadvantages of the method of non-destructive testing by holography, which do not reduce the possibilities of its application. These include: all types of work should be performed only in a darkened room, the overall dimensions of the parts are limited by the actual dimensions of the film or photographic plates; the products must be painted prior to creating a matte surface (white or silver paint), protective screens must be used and there is no way to observe the products during the experiment in real time.It should be noted that some of the above disadvantages partially reduce the efficiency from the implementation of speckle interferometry - double-pulse holography, but do not completely eliminate it from the range of modern non-destructive testing methods. Under certain conditions, correctly selected nomenclature of parts, experimental conditions, as well as complex combination with other methods, for example; computer holography, acoustic, radiographic methods, it is possible to obtain results that correspond with a high measure of accuracy to real processes, and the obtained mathematical models adequately describe the physical phenomena that take place in the details of agricultural machinery.

The minimum of microdeformation and, accordingly, the minimum of stresses correspond to the areas with the minimum reproduced intensity of light bands. On computer holograms, these bands are in the middle range of the light spectrum, as indicated by the scales shown on the holograms. By studying holograms for each type of load and type of parts. Displacement of coloured stripes on the hologram indicates the presence of damage or defects. A sharp change in colour also gives information about the presence of damage or defects. As it was established experimentally, the presence of a stress concentrator, residual stresses indicate the location of the defect under a particular surface.

These definitions are the results of experimental studies that characterize the stability of computer holograms. When conducting research, for example: elements of the investigated part (figure3) with 25-fold repetition, the computer hologram recorded almost a similar pattern, which allowed to say that this part is made without defects, has parameters within acceptable limits and can be operated effectively for a specified period of time.The study was conducted using ploughshares, which are used in tillage in agricultural enterprises.An important feature of computer holograms is that they provide information about the distribution of microdeformations on the surface of the part being studied. It is possible to study the physical processes of microdeformation not discrete, point by point, but integrally, assessing the state of the entire surface.The number of component models of the general description depended on the required accuracy given in advance, with an error of not more than β = 0.1-0.3.

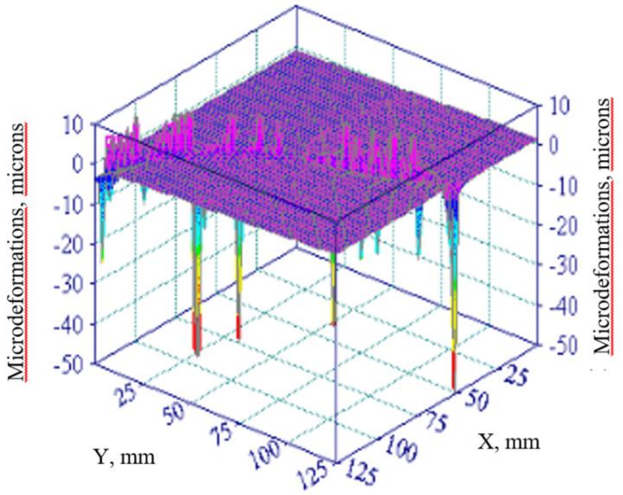

Figure 3. Mathematical model of the process of microdeformation of the ploughshare surface at its allowable load.

The presence of a scale on each hologram allows to determine the magnitude of microdeformation at each point of the studied part, to develop a mathematical model that allows to adequately describe the process of microdeformation under the action determined by the formula, type and magnitude of the load. The mathematical model in the three-dimensional image, which adequately describes the dependence of the microdeformation at the allowable load, is shown in figure3. This mathematical model is defined by a logarithmic polynomial:

$$M = f(X,Y) = (-1.0813 + 0.0104 \cdot X + 0.0255 \cdot Y - 0.6 \cdot X^2 - 0.0002 \cdot X \cdot Y) \times \\ \times (10 - 0.0097 \cdot X - 0.0081 \cdot Y + 1.139 \cdot X^2 - 0.5 \cdot Y^2)^{-1},$$

where M – microdeformations, microns, X, Y–coordinates on the surface of the hologram, mm.

Analysis of the correlation equation for a part with an existing defect shows that computer holography with a high degree of reliability describes the physical process, where: G^2 = 0.877 at G^2 = 1 => max; DF Adj r^2 = 0.867 at DF Adj r^2 = 1 => max. This indicates the adequacy of the result to the real process. The hologram has a corresponding distortion related to the presence of the defect found.Characteristic peaks and troughs on the hologram characterize the presence, structure, and to some extent, the magnitude and nature of the subsurface defect: in our case, a crack, which significantly reduces the operational reliability of the working surface of the part.

5. Conclusions

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