To a question on the possibility of using mechanoluminescent sensor elements with area-distributed sensitivity in aerospace engineering

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Abstract. This article considers the question of the possibility of using distributed mechanoluminescent sensor elements to create materials with a self-diagnostics function for use in aerospace engineering. In particular, it is proposed to use these sensor elements to monitor the condition of the shell and detect impacts and collisions. A brief description of the phenomenon of mechanoluminescence is given and the design of a sensor imitating a sheathing element is described in this article. The main attention is paid to an experimental study of simulating the collision of a solid with a composite material, which has a mechanoluminescent sensor element distributed over the area. The results of data processing are presented and made the conclusion about the possibility of using this type of structures for structural health monitoring in aerospace technique.

1. Introduction
Various sensors and automatic or automated systems are currently the main elements that ensure the safety of the operation of ground, air and space technique. In the case of equipment and systems for space purposes, it is especially possible to distinguish sensors for monitoring the integrity of the skin of aircraft. In [1, 2], it is said that sensors and sensor networks form a smart structure for monitoring the state of aeronautics objects. It is also said that these sensors are an important part of the monitoring system of the state of a technical object.

2. Mechanoluminescent materials for self-diagnostic function
The monitoring system for continuous structural health monitoring (SHM) of the object requires a constant flow of relevant information from various sensors. A network of impact sensors or the use of tactile sensors is required to monitor the integrity of the shell. For systems of structural health monitoring (SHM) in this paper it is proposed to use integrated into the material of the shell mechanoluminescent shock sensors of distributed type. Possible methods of creating composite materials using mechanoluminescent phenomenon for fracture detection are already known [3,4,5]. The researchers associate the development of condition monitoring and self-diagnosis systems with the wider use of innovative materials that would enable the functions of self-diagnosis and non-destructive testing [6].

The phenomenon of light emission in response to external mechanical action is called mechanoluminescence. The application of various mechanical influences (friction, shock, destruction)
to the mechanoluminophore causes the movement of dislocations existing in the crystal structure and
the formation of new free radicals after the bonds break. In this case, part of the excess of energy
arising through the changes in the energy states of electrons is transferred to some luminescence
centers, exciting them, which ultimately leads to the emission of photons by luminescence centers [7].
It is worth noting the generator mode of operation of this type of converters. This is a great advantage
of this type of sensors, as it is possible to provide coverage of a large area of such distributed sensors.

3. Experiments description
To investigate the possibility of using distributed mechanoluminescent pulse pressure sensors as
impact sensors and to monitor the integrity of the shell, an experimental study was conducted. A block
diagram of the conversion of mechanical action into an optical signal is shown in figure 1.

![Diagram of the conversion of mechanical action into an optical signal](image)

**Figure 1.** Scheme of conversion of impact into an optical signal of a mechanophosphor.

An experimental study of distributed-type ML sensors is aimed at analyzing its performance in
modeling external influences that reflect the actual operating conditions of external impact monitoring
systems. A sample of the sensor (Figure 2) is made in the form of a standalone device consisting of: a
steel plate (item 1) simulating the skin of an object (there were used plates with a thickness of 1 to 6
mm); flat mechanical stress concentrator (item 2) to increase the sensitivity of the sensor;
mechanoluminescent distributed sensing element (item 3); a transparent base (item 4) and a closed
optical channel for image transmission.

![Diagram of a mechanoluminescent impact sensor](image)

**Figure 2.** Structure of mechanoluminescent impact sensor for SHM.

For the manufacture of a sensor element, particles of a luminescent powder were thermally applied
between two layers of a transparent film. The resulting film sensitive element is durable and flexible.
This allows the use of such elements on surfaces of complex shape. In general, the surface area of the
distributed ML sensors of pulsed pressure can be practically any and limited only by the specific
purpose of creating the sensor. A video camera was used to register the output signal; the resulting
image was displayed on a personal computer monitor.

The experiments were carried out with sensors incorporating steel plates with a thickness of 1; 2
and 6 mm. A metal ball weighing 270 grams was chosen as the striking body. The input action was set
by the free fall of a metal ball from a certain height onto the surface of the sensor (onto a steel plate).
The contact area of the ball with the sensor surface was approximately 4 mm². The contact area was determined experimentally by the area of the imprint obtained on a steel plate after impact with a ball on the surface of which slowly drying paint was applied.

4. Experiments and data processing results
As a result of the experiments, the luminescence patterns of the phosphor shown in figure 3 were obtained.

a) impact of a metal ball falling from a height of 0.5 m on a steel plate 1 mm thick;

b) the impact of a metal ball falling from a height of 1 m on a steel plate 1 mm thick;

c) the impact of a metal ball falling from a height of 0.5 m on a steel plate with a thickness of 2 mm;

d) the impact of a metal ball falling from a height of 1 m on a steel plate with a thickness of 2 mm;
e) the impact of a metal ball falling from a height of 1 m on a steel plate with a thickness of 6 mm;

**Figure 3.** Luminescence patterns of the distributed sensor at different impacts and shell thicknesses.

All images are presented in one scale. The inhomogeneity and irregular shape of the obtained light spots are caused by the inhomogeneity of the phosphor application and the deviation of the plate shapes.

From the obtained glow frames it is clearly seen that the intensity of the glow is significantly reduced for the same input effects with an increase in the thickness of the receiver of mechanical action. In addition, for the same conditions, there is a tendency to increase the diameter of the light spot. It can also be seen that with an increase in the magnitude of the mechanical action, the intensity of the glow increases and the size of the light spot increases. For a six-millimeter plate, it can be seen that the force of the impact is not enough to excite a sufficiently bright luminescence of the phosphor.

Figure 4 shows the results of processing the images in the MatLab software.

a) processing of the image obtained after the impact of a solid falling from a height of 0.5 m on a steel plate 1 mm thick;

b) processing of the image obtained after the impact of a solid falling from a height of 1 m on a steel plate 1 mm thick;
c) processing of the image obtained after the impact of a solid falling from a height of 0.5 m on a steel plate with a thickness of 2 mm;

d) processing of the image obtained after impact by a solid falling from a height of 1 m on a steel plate with a thickness of 2 mm;

e) processing of the image obtained after impact by a solid falling from a height of 1 m on a steel plate with a thickness of 6 mm;

Figure 4. MatLab software processing of the results of the experiment.

After the software processing it is seen that the glowing areas have the shape of a circle with a peak of luminescence in the center. As can be seen, the intensity of the radiation decreases with increasing thickness of the steel plate. As the force of the impact increases, the intensity of the glow increases. As a result of the experiment, the dependence of the radiation intensity on the magnitude of the applied mechanical action is proved.

5. Summary

The experiment shows that distributed mechanoluminescent sensor elements can be used in structural monitoring systems for aerospace engineering. However, these sensors need to be further developed. For example, it is necessary to replace the open optical channel with a closed optical image transmission channel. Distributed mechanoluminescent sensors with such an information transmission channel were described in [8, 9]. It is also possible to provide localization of the scene of the collision and an assessment of the consequences of the incident. An example of creating a mechanoluminescent composite panel with SHM properties is shown in Figure 5.
Figure 5. Mechanoluminescent composite SHM panel with side input of radiation into the light guides: 1-impact object; 2-protective coating; 3-mechanoluminophore; 4-transparent substrate; 5-optical fibers with side input of light (columns); 6-optical fibers with side input of light (rows); 7-base; 8-optical fibers with end output of glow; 9-multi-element linear photodetector; 10-signal processing unit.

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