The evaluation of the possibility of using the acoustic emission method for monitoring critical membranes

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Abstract. In the article, the existing problems of production and control of membranes that collapse under the influence of internal pressure are considered. The acoustic emission method is proposed as a promising method for non-destructive testing of products. The results of full-scale tensile tests and loading by internal pressure of aluminum samples with registration of acoustic emission signals are presented. A pronounced relationship between AE signals and membrane actuation is observed.

1. Introduction

At present, membranes are widely used in aviation technology, in launching missile systems, in liquid-propellant rocket engines, in various special products and ammunition. They can be used, as sensitive, safety and functional elements [1-14]. With a sharp increase in pressure, the membrane, due to its destruction, stops the operation of the system and, thereby, prevents the consequences of an accident. As an example, consider the protection system for lithium-ion batteries installed on a Boeing 787. Safety membranes are also widely used in the chemical and oil and gas industries. The manufacturer faces the following problems:

- The main characteristic of the diaphragms is the response pressure. At the moment, there are a number of semi-empirical dependencies that make it possible to estimate the response pressure of a flat circular diaphragm fixed along the contour. But, there are no dependencies for assessing the response pressure of elements with stress concentrators (notches). An approximate estimate is made according to the dependences for flat membranes at the smallest thickness with the
introduction of additional coefficients. In addition, it can be noted that the assessment of the strength of notched membranes is carried out on the assumption of a biaxial tension pattern along the generatrix of the membrane, which is valid only for a flat membrane [2,3].

- The control of safety diaphragms consists of destructive methods. During the production phase, the manufacturer has to carry out numerous tests. With a small batch volume, the number of witness samples can reach more than 100%.

Thus, the aim of the work is to ensure 100% control of the safety membranes. The article discusses the possibility of using the acoustic emission method to control the pressure parameter of the membrane actuation.

2. Research methodology

Acoustic emission (AE) method allows you to control the quality of hard-to-reach objects during operation at elevated temperatures; assess the presence and development of a defect; possesses high sensitivity, passivity, distance [5].

At the first stage of the study, tensile tests of flat specimens made of aluminum A5M GOST 13726-97 with registration of AE signals were carried out figure 1. The chemical composition of the material is presented in table 1.

| Table 1. Chemical composition of material A5M in%. |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                 | Fe   | Si   | Mn   | Ti   | Al   | Cu   | Mg   | Zn   | Ga   |
| to 0.3          |      | 0.25 | 0.05 | 0.02 | min 99.5 | 0.02 | 0.03 | 0.06 | 0.03 |

The sensor installation diagram is shown in figure 2. The acoustic emission sensor contacts the workpiece surface through a layer of lithol, which fills the micropores between the sensor and the workpiece surface and improves the conductivity of the acoustic emission signals.

![Figure 1](image1.png)  
**Figure 1.** a) samples before testing; b) samples after testing.

The sensor installation diagram is shown in figure 2. The acoustic emission sensor contacts the workpiece surface through a layer of lithol, which fills the micropores between the sensor and the workpiece surface and improves the conductivity of the acoustic emission signals.

![Figure 2](image2.png)  
**Figure 2.** Installation diagram of samples with an acoustic emission sensor. 1-sensor AE; 2-flat sample; 3-grippers.

To assess the effect of laser processing of metal on its mechanical properties, a sample with a removed layer of material in the laser mode corresponding to the mode for obtaining a notch 0.2 mm deep was made. A photo of the sample is shown in figure 3.
Two cutting modes were used - to a depth of 0.1 mm and 0.2 mm. According to the results of the experiment, the necessary technological modes were determined. Laser modes for applying incisions: notch depth - 0.1...0.2 mm, power - 77...90%, speed - 10 mm/s, frequency 20 kHz. The view of the incisions under the microscope is shown in figure 4.

Figure 3. Sample after laser treatment.

Figure 4. View of incisions under a microscope: a) a notch with a depth of 0.1 mm; b) a notch with a depth of 0.2 mm.

3. Research results

Combined graphs "P-Δl", the dependence of the number of pulses on time and amplitude on time for sample No. 1 are shown in figure 5.

Figure 5. Combined graphs "P-Δl", the dependence of the number of pulses on time and amplitude on time for the sample a) No. 1 and b) No. 2: 1-Graph "P-Δl", 2-graph of the dependence of the number of pulses on time, 3-graph amplitude versus time.

The combined plots "P-Δl", the dependence of the number of pulses on time and amplitude on time for a sample with laser treatment are shown in figure 6.
Figure 6. Combined graphs "P-Δl", the dependence of the number of pulses on time and amplitude on time: 1-Graph "P-Δl", 2-graph of the dependence of the number of pulses on time, 3-graph of the dependence of amplitude on time.

Analysis of the given data shows that in the process of manufacturing the stress concentrator, the laser beam melts the material in the zone of action. Part of the material is thrown out of the cut zone, some freezes on the already processed surface. Thus, the mechanical properties of the material in the cutting zone are also influenced by the temperature effect. The results of the experiments showed a significant difference between the relative elongation of the two types of samples, the average value of Δl for the standard sample corresponds to 9.3 mm, and for the sample, after laser treatment, 1.3 mm, which is 86% lower. In this case, the average value of the maximum force for the standard sample is 190 N, and for the processed sample 254 N, which is 25% higher. A summary of the results is presented in table 2.

Table 2. Differences in the main characteristics of the samples.

| Calculated parameters, MPa | Standard sample | Sample with laser processing | Δ, % |
|----------------------------|----------------|----------------------------|------|
| σ0.2                       | 35             | 58                         | 40   |
| σ12                        | 70             | 103                        | 31   |
| σy                         | 160            | 180                        | 10   |
| σp                         | 160            | 187                        | 15   |

Differences can also be observed on the hardening curves shown in figure 7. From the data presented, it can be concluded that laser treatment of the A5M alloy reduces the plasticity of the material.

At the next stage of the experimental study, flat membranes without stress concentrators made of aluminum A5M were tested. The results of registration of acoustic emission signals for flat membrane No. 1 and No. 2 with gradual loading and destruction are shown in figures 8 and 9, respectively.

Peaks are noted on the amplitude graphs at the beginning of the test, which indicates an intense deformation of the membranes in the embedment area. Then, over a long period of time, the amplitude changes insignificantly, although the load is constantly growing. Bursts that can be associated with the beginning of destruction near the end are marked. At the moment of membrane rupture, the highest amplitude values are noted. On the graph of the number of pulses, a sharp increase in signals occurs at the moment of the onset of intense deformation of the membranes, then, over a long period, the number of signals practically did not change, which presumably indicates insignificant plastic deformation of the membrane. At the stage before destruction, the number of pulses began to increase again.
Figure 7. Hardening curves $\sigma_i-\varepsilon_i$ of A5M material: 1-For a standard sample; 2-For sample after laser processing.

Figure 8. Dependence of acoustic emission signals (amplitude and number of signals) on the loading time for flat membrane No. 1 at constant load: 1-Number of AE signals, 2-AE amplitude.

The final stage of research was the loading of membranes with stress concentrators (notches). The destruction of the membranes occurred only along one notch, which can be associated with the inaccurate positioning of the sheet blank on the laser table.

The combined dependences of acoustic emission signals (amplitude and number of signals) on the loading time for a membrane with a notch 0.2 mm deep are shown in figure 10.

Figure 9. Dependence of acoustic emission signals (amplitude and number of signals) on the loading time for flat membrane No. 2 at constant load: 1-Number of AE signals, 2-AE amplitude.

Figure 10. Combined graphs of the dependence of acoustic emission signals (amplitude and number of signals) on the loading time for a membrane with a notch 0.2 mm deep: 1-Amplitude of AE signals, 2-Number of AE pulses.

The combined plots of acoustic emission signals for a membrane with a notch 0.1 mm deep are shown in figure 11.

Analysis of the dependences of the number of pulses and amplitude shows a slight increase from 1 to 6 seconds of the experiment (from 0 to 2000), which may indicate elastic deformation. From 6 to 9 seconds (figure 11), a sharp increase in signals was noted (from 2000 to 13000), which corresponds to the transition from elastic to plastic deformation. From 9 to 27 seconds, a gradual increase in the number of impulses (from 13000 to 14000) and after 27 seconds, the number of impulses and the amplitude increase sharply, which corresponds to destruction.
4. Conclusion
The study proposes an acoustic emission method for controlling the response pressure of safety membranes. The results of full-scale tensile tests and loading by internal pressure of aluminum samples with registration of acoustic emission signals are presented. There is a pronounced relationship between acoustic emission signals and membrane actuation. The method undoubtedly seems to be promising for this direction and requires further development and study. Comparing the graphs of AE signals for membranes with and without notches, for the former, a greater number of peaks in amplitude and an order of magnitude (200 versus 10 thousand signals) a larger number of recorded signals are noted. Thanks to this, it is possible to identify zones corresponding to deformation in the embedding zone and in the notch zone.

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