Improving diagnostics and forecasting of the technical condition of aircraft structural elements by taking into account the impact of non-stationary gas flows

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Abstract. This paper presents the results of a study of the effect of pulsating subsonic gas flow treatment on the corrosion resistance of structural metal materials used in aircraft structural elements. The disadvantage of even the most modern methods of increasing the structural strength of metal materials is an insufficient increase in corrosion resistance. An urgent task is to develop methods for increasing the corrosion resistance of aircraft structural elements throughout their volume without additional alloying, which not only increases the cost of the product material, but also, often, makes it less producible, which can be used during the restoration of both aviation and airfield equipment. The article describes a method developed by the authors to increase corrosion resistance using pulsed subsonic gas flows. The data obtained as a result of the conducted research will allow more effective control of the corrosion condition of aircraft by non-destructive methods, as well as increase the accuracy of forecasting the technical condition.

1. Introduction
Today, a significant proportion of aircraft and aircraft engine design elements are made of metal materials that can be subjected to electrochemical corrosion. Corrosion foci may be hard to detect in a timely manner during aircraft maintenance, as they are often located in places that are difficult to access for operational (non-selective) control.

As a result of the occurrence and development of electrochemical corrosion, the strength is reduced by reducing the cross-section area of the structural elements, and the resulting stress concentrators reduce the resistance to fatigue failure, as well as increase the risk of failure as a result of shock load.

The disadvantage of even the most modern methods of increasing the structural strength of metal materials [1-8] is an insufficient increase in corrosion resistance.

Increasing resistance to electrochemical corrosion is currently implemented primarily through the use of various protective coatings. The disadvantages of this method of resisting corrosion is a sharp decrease in corrosion resistance when the coating is broken. Also, the coating prevents the use of many methods of diagnosing the technical condition.

An urgent task is to develop methods for increasing the corrosion resistance of aircraft structural elements throughout their volume without additional alloying [9], which not only increases the cost of the product material, but also, often, makes it less producible, which can be used in the course of restoration of both aviation and airfield equipment.
Mechanical processing is traditionally used in mechanical engineering to increase the resistance of products to electrochemical corrosion. Thus, polishing that smooths the protrusions on the surface of the metal part reduces the potential difference, and also prevents the retention of potential electrolyte in the cavities in the form of moisture or contamination. Creating compressive stresses on the surface of the product when running in a roller or diamond processing with a mandrel creates compressive residual stresses in its surface layers that contribute to both increased resistance to the formation and development of fatigue cracks and corrosion resistance. All these methods are quite expensive, inefficient and provide only a superficial increase in corrosion resistance, which is not enough for materials that are prone, for example, to intercrystalline corrosion.

2. Materials and methods

Studies have been carried out on the effect of non-stationary pre-sound air flow (gas-pulse processing [10]) on corrosion resistance, including to a greater depth, of various metal materials used in aircraft and airfield equipment undergoing repair. An additional task of the study was to determine and evaluate the possible negative impact of the operational impact of air currents on the corrosion state of the aircraft structural elements that were simulated during gas-pulse processing.

For example, to test the resistance to electrochemical corrosion of products made of improved steel 40 as a result of exposure to non-stationary subsonic air flow, two types of high-strength processing (the strength limit value is more than 1600 MPa) were implemented: the traditional method for such steels - quenching followed by low tempering for an hour and a half, and an experimental method in which low tempering was replaced by gas-pulse treatment lasting less than 20 minutes. After that, the samples were placed in a hydrochloric acid solution for 3 weeks. At the same time, the comparative change in mass was periodically recorded.

3. Investigation of the effect of treatment with non-stationary gas flows on the properties of steels

The decrease in the mass of samples exposed to non-stationary to sound air flow for 3 weeks was 7.14%, while in traditionally treated samples it reached a value of 10.03%.

The decrease in sample mass per unit area over 3 weeks was calculated using the formula

\[ \Delta m = \frac{(m_0 - m_1)}{S} \]

where: \( m_0 \) is the weight before test, kg; \( m_1 \) is the mass after the test, kg; \( S \) is a surface area, m\(^2\); \( \Delta m = 1.078 \text{ kg/m}^2 \) for blow-fired quenching and \( 1.495 \text{ kg/m}^2 \) for low-tempering.

The corrosion rate of \( V_c \) was 0.0539 kg/m\(^2\)-day in the case of gas pulse processing and 0.0748 kg/m\(^2\)-day in the case of quenching followed by low tempering. Comparative results of pulsating air flow treatment of Grade 40 steel for corrosion resistance are shown in Figure 1.

The higher corrosion resistance after gas-pulse treatment is due to the complete removal of tensile residual stresses, which cannot be fully achieved at low release. Also, increased corrosion resistance in comparison with standard thermal hardening is associated with less intensive formation of secondary carbides that have an electrode potential different from the martensitic phase.

As a result of experimental treatment, the hardness of the steel is 2 Rockwell units higher than the hardness of the traditionally tercoated steel, which contributes to increased wear resistance. At the same time, the resistance to shock loads is not lower than after standard heat treatment, thanks to the complete removal of tensile residual stresses.

The effect of pulsed air flow treatment on the resistance to electrochemical corrosion of 40X alloy steel being improved using a similar method was also investigated.

According to the results of the tests, the decrease in the mass of samples for 3 weeks did not exceed 2.8% in the case of using pulsating air flow treatment and reached 3.5% in the absence of such treatment.

Comparative results of the effect of pulsating air flow treatment on the corrosion resistance of 40X steel are presented in the form of graphs figure 2.
Figure 1. Comparative results of the effect of pulsating air flow treatment on the corrosion resistance of steel 40.

Figure 2. Comparative results of the effect of pulsating air flow treatment on the corrosion resistance of 40X steel.
For Grade 40X steel, as in the previous case, there was an increase in hardness in comparison with standard heat treatment without reducing the viscosity.

Further research was carried out on the effect of pulsating air flow treatment on the corrosion resistance of 12XH steel, which is used in aviation and airfield equipment for gears, fingers and other critical parts that work under dynamic influences and cyclic loads.

This steel was subjected to gas pulse treatment lasting up to 15 minutes.

Studies of the effect of pulsating air flow treatment on corrosion resistance, as in previous cases, were carried out using a hydrochloric acid solution, in which samples, both subjected to gas-pulse treatment and untreated, were kept for 2 weeks with periodic mass measurement.

The test results showed that the weight reduction in the case of using gas-pulse processing is almost a quarter higher than without it (table 1).

### Table 1. Comparative results of the effect of pulsating air flow treatment on the mass of 12XH steel samples exposed to aggressive media.

| Processing            | Weight loss, g. |
|-----------------------|-----------------|
|                       | 0    | 7 days | 15 days |
| Delivery condition    | 31.03 | 30.86  | 30.16   |
| Gas pulse processing  |      |        |         |
| 12 min                | 30.9  | 30.77  | 30.24   |

At the same time, in general, for steels, the volumetric nature of the impact of pulsating air flow treatment on corrosion resistance is manifested in the fact that the deeper the corrosion penetrates, the higher the comparative corrosion resistance of steel products subjected to gas-pulse treatment.

However, prolonged exposure to subsonic air flows (more than 20 minutes) can negatively affect corrosion resistance, which must be taken into account when predicting the technical condition of aircraft structural elements.

4. **Investigation of the effect of treatment with non-stationary gas flows on the properties of aluminum alloys and coatings**

Aluminum alloys are widely used in aircraft construction and assessing the impact of non-stationary air flows on their corrosion resistance is an important issue in the operation, maintenance and repair of aircraft.

The effect of pulsating air flow treatment on the corrosion resistance of the deformable 1560 aluminum alloy was investigated. The processing time was less than 20 minutes, the processing was one-way and the air flow was directed to the plane of the sample, which was a plate.

Research was carried out using a solution of hydrochloric acid, and instead of the four-percent solution used in corrosion tests of steel, a ten times more concentrated solution was used.

As a result, the reduction in mass over five days of testing was significant: the sample subjected to gas-pulse treatment lost almost 13% of its original mass, while the mass loss of the sample that was not subjected to gas-pulse treatment exceeded 60% (Figure 3).

The influence of gas-pulse treatment on the stability of coatings, in particular chrome ones, on the surface of thin-walled tubes, which are typical for aircraft undergoing repair, was also studied.

The chrome-plated brass tube was subjected to corrosion tests in hydrochloric acid solution after being treated with a pulsating air stream.

Comparative results of the effect of pulsating air flow treatment lasting up to 20 minutes on the resistance of the chrome coating to HCl solution indicate a positive result of such treatment.
5. Conclusion
As a result of the study, a technical result was obtained that will increase the corrosion resistance of repaired parts of aviation and airfield equipment made of structural steels and non-ferrous alloys to a significant depth.

The obtained data will allow for control over the aircraft corrosion conditions that is more effective and achieved by non-destructive methods, as well as for improvement in the accuracy of forecasting the technical condition.

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