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Dmytro O. Shevchuk, Candidate of Engineering, assoc. Prof.

FIBER-OPTIC INTELLIGENCE SYSTEMS FOR DIAGNOSTICS CONTRACTION INTEGRITY OF AIRCRAFTS

National Aviation University
E-mail: dmitroshevchuk@gmail.com

Article is devoted to the possibilities to use the fiber-optical intelligence structure for the diagnostics contraction integrity of aircrafts.

aircraft, fiber-optic intelligence structure, fiber-optic sensors, neuron network

Introduction

In foremost aviation and space equipment the contemporary technologies of measurements are necessary both for the observation of a change in the environment and for the diagnosis, and also evaluating the design integrity of aircraft.

For registering of ambient conditions and internal processes of degradation with influence of which the technical state of aircraft is changing and in the process of operation a constant test of the parameters is achieved, which characterize the technical state of the outline of the aircraft.

To this time the diagnostics of the state of the aircrafts outline in the process of its operation is being the most undeveloped, which most of all experiences the influence of the external mechanical, biological, electromechanical and electrical degrading factors [1-3].

Analysis of research and publications

Sizes, weight, insensitivity to the electromagnetic interferences, the increased strength and protection from the actions of environment are the basic factors, which influence the selection of the technologies to use for the fixation of place, degree and time of the standard damage of the external circumscription of aircraft in the process of its operation. The obtained diagnostic information will make it possible to automatically change the control law (to reconfigure control), i.e., to be adapted to the prevailing special situation and thus to avoid accidents during the flight.

Nowadays, the fiber technology that is used for the problem solution of the integrity diagnosis of the external circumscription of aircraft has a number of advantages in comparison with the electronic technology [4−9]:

− low weight and convenient layout;
− completely passive network;
− the use of small power;
− insensitivity to the electromagnetic interferences;
− high sensitivity and wide passband;
− compatibility with the optical transfer and data processing;
− the prolonged period of operation and low cost.

The fiber-optic diagnosing systems can be light weighted and easy to arrange because of their small sizes. In particular, fiber can be injected in the material of any fragment of the lifting surface of aircraft. In this case the common design features of fragment itself will change very insignificantly.

The fact that the diagrams with the use of fiber-optic systems of the diagnosis of the design integrity of aircraft are electrically passive, is very important, because the situations when the appearance of the conducting path can lead to the catastrophic consequences, such as sparking. The use of small power is substantial for the systems where large number of sensors used that are located along the outline of the lifting surface of aircraft.

Insensitivity to the electromagnetic interferences of fiber-optic intellectual systems makes it possible to avoid the need to solve problem of screening weak electrical signals, which go from the sensors and need to put big cable through. This advantage becomes even more influential, when the large number of sensors is united into the massif. If these sensors have high sensitivity and large dynamic range, the required passband of massif will prove to be sufficiently wide. Since multiplexing diagnostic information from the sensors with the use of a wide-band optical fiber is necessary, that is potentially capable to support the transfer of signals with thousands of sensors, this kind of problem will be avoided.

The listed advantages are especially important for the fiber-optic intellectual systems of the diagnosis of the design integrity of the aircraft, where the wide range of measuring possibilities and stability to the extreme ambient conditions with the minimal sizes and the weight is required.

Goal of the article − development of fiber-optic intellectual system for the diagnosis of the design integrity of aircraft in the process of its operation.

Primary Part

In the article is being proposed to examine the possibility of use fiber-optic intellectual systems, for evaluating the structural integrity of the aircraft before the takeoff and in during the flights. The fiber-optic intellectual system of the diagnosis of the external circumscription of aircraft, can be used in the process of operation, i.e., both during the flight and during the maintenance. The second function of the complex of fiber-optic sensors in the modern aircraft, is the measurement of the external parameters, such as temperature, pressure and recording place, degree and time of impact, which makes possible for aircraft to fly closely to the range of the regimes of safe operation assumed construction, without exceeding its limits, or to classify standard damages arisen in flight.

Lest analyze the dynamics of the controlled flight of aircraft under the conditions of the appearance of the standard damage of outline. The dynamics of the motion of aircraft as the object of control under the conditions of damaging the outline is described by differential equation of motion [10]:

$$\dot{x} = f(x, a, u, z, t) + \xi_x, \tag{1}$$

where $x = [x_1, ..., x_i]$, $i = \overline{1, n}$ is the vector characterizing the state of aircraft under the conditions for standard damage; $a = [a_1, ..., a_j]$;

$j = \overline{1, r}$ is the vector of the parameters determined by the qualities of environment;

$u = [u_1, ..., u_k]$, $k = \overline{1, m}$ is the vector of the controlling influences, formed by pilot or autopilot, depending on the stage of flight;

$z = [z_1, ..., z_n]$ $n = \overline{1, q}$ is the vector characterizing the influence of standard damage on aerodynamics of aircraft;

t is the current time of motion, which belongs to the section $[t_0, t_к]$ on which is determined the equation (1);

ξ is the vector of disturbances.

For the analysis of dynamic characteristics, the aircraft under the conditions for the standard damage of outline is represented as system with six degrees of freedom. The dynamics of the motion of this system is described by the system of equations that including:

− the dynamic equations, which describe the motion of its center of masses considering a change in the aerodynamic properties of the external circumscription of aircraft;

− the dynamic equations, which describe the motion of aircraft relative to its center of masses, taking into account a change in the aerodynamic properties of the outline of aircraft.

In accordance with the rule of conservation of quantity and moment of momentum, we are writing down these vector equations:

− equation, that describe the motion of the center of the masses of aircraft taking into account the development of the standard damage of the external circumscription of the aircraft:

$$m\dot{\vec{V}} + m\vec{\Omega} \times \vec{V} = \vec{F}, \tag{2}$$

where m is the mass of aircraft,

$\vec{V}$ is the velocity vector of the motion of the center of the masses of aircraft relative to the air medium, not agitated by aircraft in the inertial reference system;

$\vec{F}$ is the total vector of all external forces, which act on the aircraft in flight;

$\vec{\Omega}$ is the vector of the absolute angular rate of rotation of the arbitrary coordinate system.

The total vector of all external forces of those acting on the aircraft under the conditions of the appearance of standard damage in flight represent in the form the sums of the vectors:

$$\vec{F} = \vec{F}_{\text{aer}} + \vec{F}_{\text{ext}} + \vec{F}_{\text{t.c.}}$$

where $\vec{F}_{\text{aer}}$ is the force, which is created as a result of the deflection of the aerodynamic surfaces of aircraft;

$\vec{F}_{\text{ext}}$ is external force acting on the aircraft, that arose as a result of the appearance of the gusts and turbulence;

$\vec{F}_{\text{t.c.}}$ is the force vector appearing as a result of a change in the aerodynamic properties of the external circumscription of aircraft.

The equation, which describes the motion of aircraft relative to its center of masses taking into account standard damage, let us represent in the form:

$$\dot{\vec{L}} + \vec{\Omega} \times \vec{L} = \vec{M}$$

where $\vec{L}$ is the vector of the moment of motion of aircraft;

$\vec{M}$ is the total vector of the moments of those acting on the aircraft:

$$\vec{M} = \vec{M}_{\text{aer}} + \vec{M}_{\text{ext}} + \vec{M}_{\text{t.c.}};$$

where $\vec{M}_{\text{aer}}$ is the moment, which appears as a result of changes in the position of the aerodynamic surfaces of aircraft;

$\vec{M}_{\text{ext}}$ is the moment, which acts on the aircraft and which arose as a result of the appearance of the gusts and turbulence;

$\vec{M}_{\text{t.c.}}$ is the vector of the moment, which arisen as a result of the development of standard damage in flight.

In the body coordinate system the expression (2) can be represented in the matrix form [10]:

$$m\begin{bmatrix}\dot{V}_{kx}\\ \dot{V}_{ky}\\ \dot{V}_{kz}\end{bmatrix}+m\begin{bmatrix}V_{kz}\omega_y-V_{ky}\omega_z\\ V_{kx}\omega_z-V_{kz}\omega_x\\ V_{ky}\omega_x-V_{kx}\omega_y\end{bmatrix}=\vec{F},$$

where $\vec{F}$ is the resulting force vector, which also considers the influence of standard damage, represented in the projections on the axis of body coordinate system;

$\omega=[\omega_x,\omega_y,\omega_z]$ is the angular velocity vector of the rotation of body coordinate system.

The resulting vector of the external forces, which act on the aircraft under the conditions of the appearance of standard damage in the general case in flight, includes [10]:

$$\vec{F}=\vec{G}+\vec{P}+\vec{R}+\vec{\Lambda},$$

where $\vec{G}$ is the vector of the force of gravity of aircraft;

$\vec{P}$ is the vector of the thrusts of engine;

$\vec{R}$ is the resulting vector of aerodynamic forces;

$\vec{\Lambda}$ is the additional vector of the forces, which act on the aircraft as a result of the appearance of standard damage in flight.

The aerodynamic forces, which act on the aircraft, are determined by its configuration and nature of the flow around aircraft of the incident air flow [10]:

$$R=\begin{bmatrix}X\\ Y\\ Z\end{bmatrix}=qS\begin{bmatrix}c_x\\ c_y\\ c_z\end{bmatrix}$$

where q is velocity head:

$$q=\frac{\rho V^2}{2};$$

S is the wing area of aircraft, washed by the incident flow;

c_x, c_y, c_z are dimensionless coefficients of aerodynamic forces that including considering influence standard creations of the external circumscription of aircraft.

For the diagnosis of the internal progressive structural destruction it is proposed to use the mechanical-luminescent sensors, the principle of work of which is based on the phenomenon of mechanical luminescence − appearance of optical radiation (photon emission) inside solid bodies as a result of the deformation.

Mechanical-luminescent sensors are incorporated in the structure of composite and convert energy of mechanical stress into the optical signal, which can be transferred by the quartz fibers, which reinforce the layers of polymeric matrix, to the block of processing signals (classifier).

This fiber-optic intellectual structure, builds it the composite material, possesses the properties of self-diagnosis and can be used for the recognition of place, degree and type of damage. The structure of intellectual fiber-optic material is schematically depicted to fig. 1.

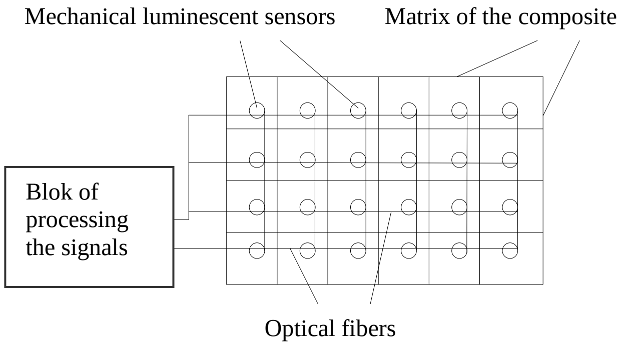

Fig. 1. The structure of the intellectual fiber-optical material, connected with the block processing the signals

Advantages of the use of the intellectual composite materials:

− the primary data carrier - the flow of photons is its own product of the process of a change of state of substance, i.e., they are not required special actions and straight contact with the material for obtaining the information;

− information will be transmitted to the photoreceiver, registering apparatus from "speed of light" − it is practically inertia-free, which makes it possible to record the damages in real time, which appear during the flight (dent, breaks, chippings, the breaks of edging so forth);

− information about the damages can be obtained both integrally and locally, i.e., the most operational possible determination of the position, degree and time of the appearance of the damage to lifting surface of aircraft in the flight, which will make it possible to reconfigure control of aircraft and to thus avoid flight accidents.

The task of the block of information processing is the classification of the standard damages of external circumscriptions in flight, and also the tracking of the appearance of destructive processes in the structure of composite skin materials. Examples of the standard damages: the damage of skin and mechanization of wing and of tail assembly, which they lead to a change in the forces and moments, which act on the aerodynamic surfaces, with the subsequent course deviation; collision with the birds; the impacts of stones with the takeoff and the landing. As the block of processing information (classifier) it is intended to use an artificial neuron network named after Kohonen (fig. 2).

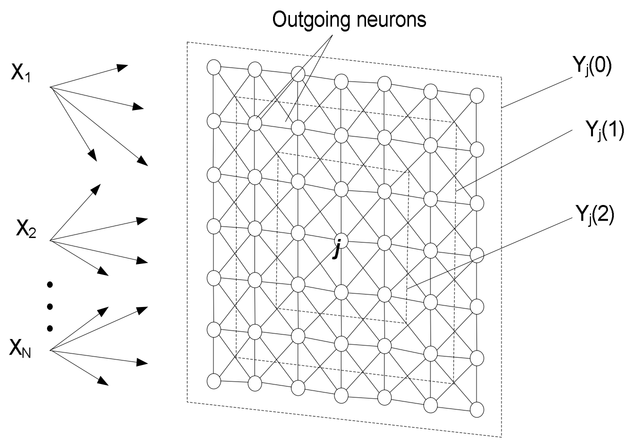

Fig. 2. Artificial neuron network named after Kohonen:
$x=[x_1,...,x_N]$ is vector of input values, which characterizes the integrity of the outline of aircraft;
$y=[y_1,...,y_J]$ is the classes of the typical damages of the external circumscription of the aircraft

With the instruction of this map (fig. 2) there is no control of the process of tuning weight coefficients.

The study is made with use of the independent from the task measure of the quality of the classification of the standard damages of aircrafts outline.

The parameters of network are optimized relatively to this measure.

Among the vectors of those representing study, compulsorily must be the vector, which reflects "perfect" state of the external circumscription of aircraft, i.e., without the damages.

Each initial neuron with a quantity of entrances of the elements of input vector equal to a quantity, gives an output one of the values D. Initial neuron with the maximum value will determine the class, to which belongs the input information description of the integrity of the external circumscription of the aircraft $\max D(x(\omega)) = R_k(\omega)$.

By neuron conqueror is considered the neuron, which has at the entrance of the function of the activation n^1 maximum value. Activation function appropriates to this neuron at the output a^1 values 1, all other neurons have original value the equal to zero. Study of the map is achieved according to the principle [11]:

$${}_iIW_{11}(q) = {}_iIW_{11}(q-1) + \alpha(x(q) - {}_iIW_{11}(q-1))$$

where i is the number of that line of the matrix of weights, which is corrected;

${}_iIW_{11}$ i-number are concealing the line of the matrix of weights;

q is the number of the step of instruction;

α is the parameter of the speed of instruction;

$x(q)$ is the input vector of the information description of the integrity of the external circumscription of aircraft.

The weight coefficients of neurons adjacent to the conqueror change according to the rule named after Kohonen [11]:

$${}_iw(q) = (1-\alpha)\cdot{}_iw(q-1) + \alpha x(q)$$

where ${}_iw(q)$ is the weight coefficients of neurons i-number line of the matrix of weights.

By the essential advantage of the map of Kohonen there is that the fact that it insensitive to the correlation of the elements of the vector of the information description of the technical state of the aircrafts outline, since the competing principle of instruction is used. Before the instruction it is necessary to assign the topology of map and to indicate its dimensionality.

Neurons are placed in the mesh points. The indices, which characterize the map of Kohonen are the distances between the neurons (11):

− the Euclidean distance between the neurons:

$$d_1 = \sqrt{\sum (px_i - px_j)^2},$$

where px_i, px_j are the state vectors of neurons x_i and x_j;

− the distance of the maximum coordinate displacement of adjacent neuron from the base (in the cluster):

$$d_2 = \max | px_i - px_j |;$$

− the distance of connection, which shows a quantity of the units, which must be passed in order to connect the neurons x_i and x_j.

If S neurons $i = \overline{1, S}$ are assigned, then:

$$d_3 = d_{ij} = \begin{cases} 1, \ d_1 \le 1; \\ 2, \ \forall k, \ d_{ik} = d_{kj} = 1; \\ \dots \\ N, \ \forall (k_1, k_2, \dots, k_N), \ \mathrm{d}_{i,k_1} = d_{k_1 k_2} = \dots = d_{k_N j} = 1; \\ S, \ \text{in other cases} \end{cases}$$

the sum of the distances of maximum coordinate displacement between the neurons:

$$d_4 = \sum \ | px_i - px_j |,$$

that in the case of rectangular lattice coincides with d_3.

Before the instruction in neuron network of Kohonena it is necessary to conduct the procedure of rate setting the values of the vectors of information description for guaranteeing the identical speed of the instruction of weights.

Rate of vectors can be achieved in a next way.

1. For each of the elements of the vector of the information description x_i we should determine the minimum and maximum b value.

2. Each of the elements of the vector of information description to normalize to the interval [-1, 1] according to the formula:

$$x_i^{norm} = 2(x_i - a)/(b - a) - 1.$$

As a result we will obtain the collection of values from the interval [-1, 1] with the proportional to the original values of rate setting.

Weight coefficients of the network w_{ij} we will consider the components of the nuclei of the classes $\{c_k\}$ describing the standard damages of the external circumscription of aircraft.

In the stage of instruction the map of Kohonen builds mapping the collections of the values of the set of the current information descriptions of the technical state of the external circumscription of aircraft into the map of the states of the system $\{| x(\omega_h) |_{h=1}^{m}\} \to R_k(\omega)$. In the stage of operation the map ensures the classification of the current state of the external circumscription of the aircraft: $\{| x_i(\omega) |_{i=1}^{n}\} \to k$ or $\{| x_i(\omega) |_{i=1}^{n}, | z_j(\omega) |_{j=1}^{q}\} \to k$, $k \in K$.

The network of neurons of Kohonen gives the possibility to obtain the map of the classes of the technical state of the external circumscription of aircraft.

Conclusion

For the problem solution of the diagnosis of the technical state of the aircraft wing outline during the flight it is necessary to inject the new systems of diagnostics based on the fiber-optic intellectual structures, which will make it possible to estimate in proper time and objectively the technical state of the external circumscription of aircraft in the process of its operation.

For recording of place, degree and time of the suddenly emergent damage to lifting surface of aircraft during the flight it is proposed to use fiber-optic sensors, and as the classifier of standard damages a neuron network, which will increase accuracy, speed and authenticity of the recognition of the standard damages of the external circumscription of aircraft in the process of its operation.

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Д.О. Шевчук

ВОЛОКОННО-ОПТИЧНІ ІНТЕЛЕКТУАЛЬНІ СИСТЕМИ ДЛЯ ДІАГНОСТУВАННЯ КОНСТРУКТИВНОЇ ЦІЛІСНОСТІ ЛІТАКІВ

Національний авіаційний університет

волоконно-оптичні датчики, волоконно-оптичні інтелектуальні структури, нейронні мережі, повітряний корабель

Розглянуто можливість діагностування цілісності зовнішнього обводу літака у процесі його експлуатації, а також визначення ступеня, місця та часу виникнення типового пошкодження і вплив його на аеродинамічні властивості літака. Для вирішення поставленого завдання запропоновано використовувати волоконо-оптичну інтелектуальну систему, до складу якої входять механолюмінісцентні датчики, що вбудовуються в структуру композита та перетворюють енергію механічної напруги в оптичний сигнал. Для класифікації типових пошкоджень використовується нейронна мережа Кохонена. Розглянуто метод навчання нейронної мережі Кохонена. Наведено математичний опис впливу типового пошкодження на аеродинаміку літака.

Д.О. Шевчук

ВОЛОКОННО-ОПТИЧЕСКИЕ ИНТЕЛЕКТУАЛЬНЫЕ СИСТЕМИ ДЛЯ ДИАГНОСТИКИ КОНСТРУКТИВНОЙ ЦЕЛОСТНОСТИ САМОЛЕТОВ

Национальный авиационный университет

воздушное судно, волоконно-оптическая интеллектуальная система, волоконно-оптические датчики, нейронные сети

Рассмотрена возможность диагностирования целостности внешнего обвода самолета в процессе его эксплуатации, а также определение степени, места и времени возникновения типового повреждения и влияние его на аэродинамические свойства самолета. Для решения поставленной задачи предложено использовать волоконно-оптическую интеллектуальную систему, в состав которой входят механолюминесцентные датчики, встраиваемые в структуру композита и преобразовывающие энергию механического напряжения в оптический сигнал. В качестве классификатора типовых повреждений используется нейронная сеть Кохонена. Рассмотрен метод обучения нейронной сети Кохонена. Приведено математическое описание влияния типового повреждения на аэродинамику самолета.