Experimental and Computer Modeling of Intelligent Polymeric Composite Structures with Neural-Network Based Control

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Abstract— **The problem of cantilever polymeric-composite plate vibration damping with piezoelectric sensors and actuators was examined. On the basis of finite element and neural network technologies the synthetic model of active damping vibrations in anisotropic plate was created. Our numerical simulations have shown a good correspondence with experimental results on thin composite cantilevered plate active vibration damping.**⊗

I. INTRODUCTION

The greater attention in both academic and industrial communities are now receiving to a problem of development and model description of intelligent structures with control on the basis of sensors and actuators with feedback on displacements and velocities [1], [2], [3], [4] etc. As a rule, as the purpose of control the given surface shape (in static problems) and active damping of oscillations in the operational frequencies range or on separate modes appears. In a series of investigations a neural network (NN) based control system was used. The principles of learning and operation of NN can be various [5], [6], [7], [8], [9] etc. For successful fulfillment of intelligent monitoring systems and states identifications it is necessary to provide the set of learning samples contained all situations including emergency in controllable plant. This fact requires the total information on dynamics of controllable plant and its behavior at failures anyone a component.

II. ARCHITECTURE OF NEURAL NETWORK (NN) BASED CONTROL SYSTEM

As controlling system we proposed to apply a neural network controller with a reference mechanical system (Fig. 1). Such system can be mathematical model, e.g., finite element (FE) model. In the beginning a model identification of a controllable mechanical system is yielded, then training of the neural network controller so that the output of controllable plant has match follows to an output of reference model.

The structure of both neural networks contains a number of hidden layers, dependent by complication of controllable system - plant. The set of the controller input signals include: a delayed input of reference model; a delayed output of controller; a delayed output of a controllable system. The magnitude of delays can vary, being augmented with complication of a controllable plant. The network simulative mechanical systems include two set of inputs: a delayed output of the controller; and delayed output of plant. The magnitude of delays also is regulated in accordance with complication of controllable system behavior.

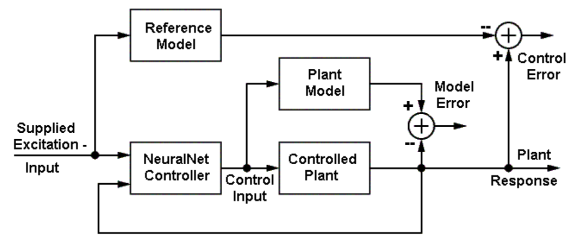

Figure 1. Architecture of control system based on reference model

Due to applicability to the broadest class of systems and speed of real-time operation the architecture of control with reference model is most perspective. It requires major volume of computational operations at a stage of the controller neural network training and well balanced reference model. Besides, that training with the help of a real mechanical system is difficultly implemented; an adequate model of the most controllable system is necessary. In a viewed case it is the mechanical model of helicopter main rotor blade. The most perspective direction is the design of a rotor blade finite element model and execution on it numerous numerical experiments with the purpose of development of learning sets. As reference model can be utilized an extreme simplified analytical or finite element model, maximum closest on dynamic responses to an actual controllable structure. An indispensable requirement superimposed on reference model, is it much improved behavior in critical situations (flutter, local damage etc.) at the expense of a heightened rigidity and structural (often nonlinear) damping.

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III. FINITE ELEMENT (FE) MODELS

As mentioned above, as standard mechanical model it is possible to utilize FE model of an elastic structure. We considered two such models: thin cantilevered plate from glass-epoxy composite (Fig. 2) with sizes 227×10×0.5 mm and simplified model of helicopter main rotor blade (Fig. 3 at the left), gimbaled in комлевой of a part. The oscillations are excited by an electromagnet (EM). Near the anchored edge installed two piezoelectric elements (PE); one of which works as sensor and another - as actuator. One more is applied also by sensor - optical displacement-meter (ODM). The results of the structure modal analysis in FE-package ACELAN are shown in Table 1.

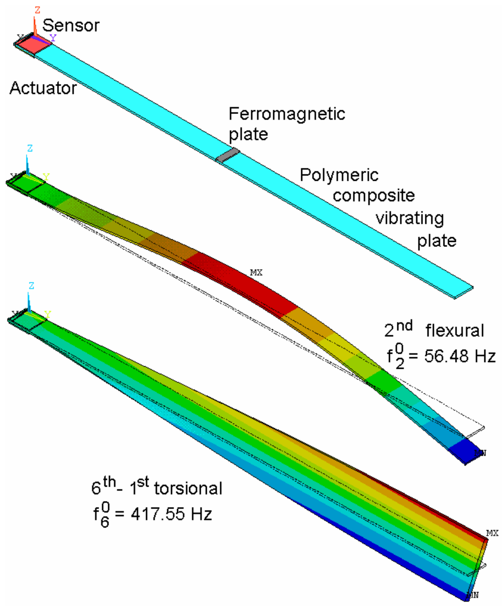

Figure 2. Flexural and torsional vibration modes of polymeric composite plate for experimental investigation

TABLE I.
FE – ANALYSIS OF VIBRATING COMPOSITE PLATE[1]

No of modes	Eigen-frequency, Hz	Mode description
1	9.04	1st flexural in plane with smallest stiffness
2	56.48	2nd flexural in plane with smallest stiffness
3	99.58	1st flexural in plane with greatest stiffness
4	157.59	3rd flexural in plane with smallest stiffness
5	308.52	4th flexural in plane with smallest stiffness
6	417.55	1st torsional

[1] – see Fig. 2

In Table 2 the results of active vibration damping on different modes are demonstrated. As an objective function of a control system for vibration damping such functional was utilized

$$F(u_z) = \int_0^L u_z^2(x) g(x) dx , \quad (1)$$

where $g(x)$- weight function; here utilized $g(x) = \delta(x - L)$ (L - length of a plate). Composite plate harmonically excited by electromagnet through small ferromagnetic plate according to law *exp(iωt)*.

For three-dimensional FE-model of full-scale composite rotor blade with root fixed in elastomeric bearing the modal analysis also carried out. These results are shown in Table 3. It is necessary to note that the eigenfrequency of the first torsional mode is close to eigenfrequency of 4th flexural mode of oscillations in a plane of the smallest stiffness. It is undesirable and can result in flexural - torsional flutter. In customizations of vibration damping system controlling the special attention was given to this frequency range.

TABLE II.
VIBRATION DAMPING BY ANALOGUE CONTROL SYSTEM
(NUMERICAL SIMULATION)

Frequency, Hz	[1]Sensor's output, V	Actuator's potential, V	Amplitude of displacement, mm	
			(without feedback)	(with feedback)
8.5	-5.8-3i	100	14.0	6.7
52.5	-0.27-0.43i	60	0.17	0.059
157.0	-0.65 -1.29i	80	0.24	0.092

[1]Imaginaire part describe a phase shift caused by acoustic impedance of air

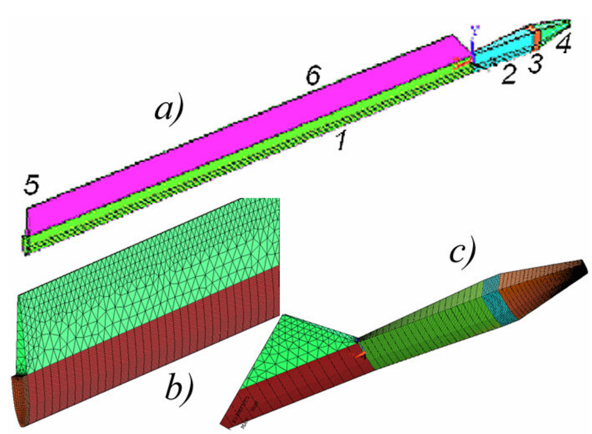

Figure 3. FE - model of the fully articulated helicopter main rotor blade created in ANSYS

a – subdivision of blade on parts with different mechanical properties;
b – model's FE - meshing near blade tip;
c – model's FE - meshing near blade root.

TABLE III.
FE – ANALYSIS OF VIBRATING HELICOPTER ROTOR BLADE[1]

No of modes	Eigen-frequency, Hz	Mode description
1	2.14	1st flexural in plane with smallest stiffness (in plane of thrust)
2	6.68	2nd flexural in plane with smallest stiffness
3	7.93	1st flexural in plane with greatest stiffness (in plane of rotation)
4	15.16	3rd flexural in plane with smallest stiffness
5	24.19	2nd flexural in plane with greatest stiffness
6	28.04	4th flexural in plane with smallest stiffness
7	29.93	1st torsional

[1] – see Fig. 3

IV. EXPERIMENT

Experimental investigation of vibrating composite structure's controllable damping was carried out on experimental setup shown on Fig. 4. The control circuit is introduced in a simplified form on Fig. 5 (inset in the left-hand upper corner). On this scheme the following labels are: Gn - generator, Sc - oscillograph, Fc - frequency counter, Am - amplifier, Pt – phase transformer. The results of some experiments on excitation and active damping of oscillations in a thin composite plate are shown in Fig. 5 and Fig. 6. In a Fig. 6 for the first mode the oscillogram of vibratory process before and after actuator . In central part of oscillogram the transient process was shown.

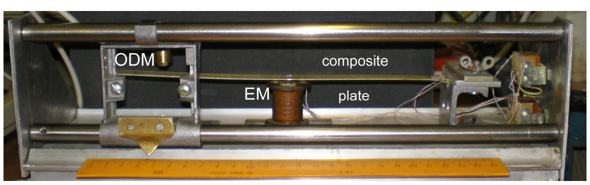

Figure 4. Experimental setup

V. CONCLUSION

For design of rotor blade mathematical models with different degrees of complication (1D, 2D, 3D) the software allow importing all nesessarie geometrical and mechanical properties from CAD-model designed. On this basis the FE - models of a helicopter rotor blade are constructed and their dynamic analysis permitting to rationally place the load-bearing elements of control is carried out. The computer simulation of system of active oscillations damping is carried out on the basis of one-dimensional, two- and three-dimensional FE models. The analysis of their operation establishes influence of different feedback types. For embodying this feedback the programmatic module connected to FE - complex ACELAN designed. The module allows to solve non-stationary problems of oscillations in a 2D case at presence of feedback between sensors and actuators. With this module FE - model of a polymeric composite plate with a piezoelectric sensor and actuators is numerically invested. The natural experiment with a similar construction controlled by analogue system and numerical experiments have detected good concurrence.

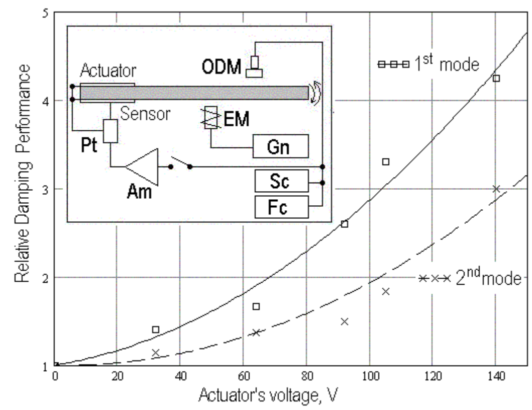

Figure 5. Feedback effect on vibration damping performance

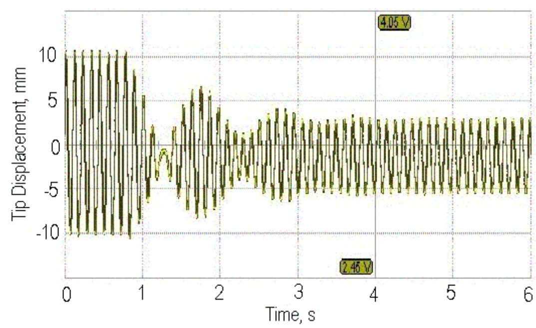

Figure 6. Time chart of transition at analogous control run-up

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