PRE-STRESSED ULTRASONIC SENSOR FOR STRUCTURAL HEALTH MONITORING

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Structural health monitoring (SHM) of aircraft will be successful, if two minimal requirements are obeyed: 1) SHM system is able reliably detect all kinds of structural damages, and 2) Own reliability of SHM system is high. In ultrasonic SHM system the least defended element is a piezoceramics transducer integrated in structure. Conditions of aircraft operation are very complex: mechanical loading and vibration, environmental degradation, wide range of temperature and others. In many cases the special protection is needed.

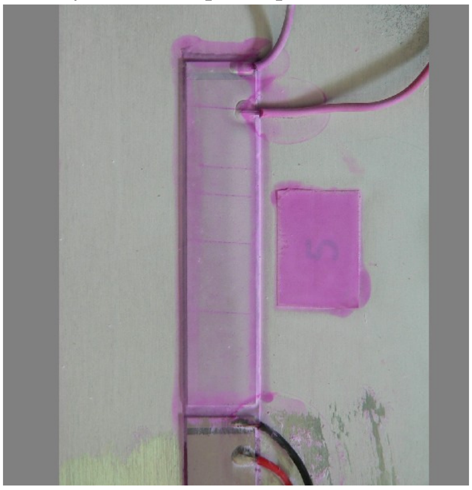

Figure 1. The cracks in piezoceramics

For example, Figure 1 showed a piezoceramics 0.5x10x50mm transducer installed to an Al panel after about 60000 cycles of loading with the stress amplitude 100 MPa. The transducer was glued on a skin of panel in direction of load action. This level of stress is typical for Al alloy structure of aircraft. At list nine fatigue cracks on a surface of the transducer were detected by penetration. The protection of a transducer from corrosion also is actual problem.

A type of pre-stressed transducer was created for protection from mechanical fatigue and the extreme peak of ultimate load (Figure 2). Special device was designed and made for creation of initial compressed stress in piezoceramics which strength at compression (600MPa) much more than at the tensile. This pre-stressed piezoceramics transducer can be glued along active surface ***1*** to a structural element and common tensile stress can be decreased to admissible level.

Investigation shows the sensitivity of pre-stressed transducer also decreases, but is sufficient for normal functionality of SHM. This paper is mainly focused to analysis of the electro-mechanical properties of pre-stressed transducer.

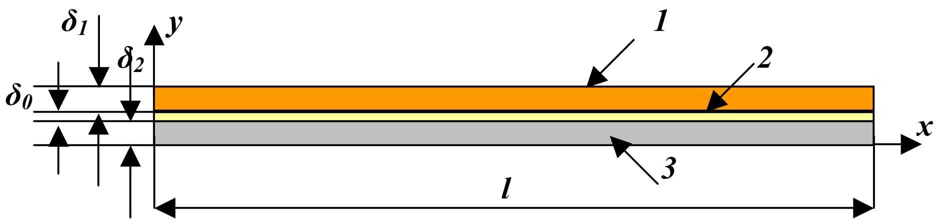

Figure 2. Piezoceramics transducer ***1*** with Al alloy overlay ***3***,
glued by Epoxy past layer ***2***

System of differential equations for the one-dimensional model of elastic wave propagation is:

$$\rho_1 A_1 \frac{\partial^2 u_1}{\partial t^2} = E_1 A_1 \frac{\partial^2 u_1}{\partial x^2} - \tau b_1 = E_1 A_1 \frac{\partial^2 u_1}{\partial x^2} - \frac{2G_1 b_1 (u_1 - u_{10})}{\delta_1}$$

$$\rho_2 A_2 \frac{\partial^2 u_2}{\partial t^2} = E_2 A_2 \frac{\partial^2 u_2}{\partial x^2} - \tau b_2 = E_2 A_2 \frac{\partial^2 u_2}{\partial x^2} - \frac{2G_2 b_2 (u_2 - u_{20})}{\delta_2}$$

$$\tau = G_1\gamma_1 = G_2\gamma_2 = G_0\gamma_0 \qquad \rightarrow \qquad \begin{cases} \dfrac{u_1 - u_{10}}{u_{20} - u_2} = \dfrac{G_2}{G_1}\dfrac{b_2}{b_1}\dfrac{\delta_1}{\delta_2} \\ \dfrac{u_{10} - u_{20}}{u_1 - u_{10}} = 2\dfrac{G_1}{G_0}\dfrac{\delta_0}{\delta_1} \end{cases}$$

where u_i, ρ_i, E_i, G_i, A_i, b_i, δ_i are axial displacement, density, elastic modulus, shear modulus, cross-section area and its width and thickness for each layer (i=0,1,2).

It is supposed that axial displacement is linearly distributed along axis ***y***. Density of the glue layer is accepted equal to zero. Solution was accepted in a standard form:

$$u_1(x,t) = U_1(x)e^{i\omega t} \qquad\qquad u_2(x,t) = U_2(x)e^{i\omega t}$$

Finally it gives the equations system:

$$\overline{U}_1'' + \left[(\gamma_1 l)^2 - (\alpha_1 l)^2\right]\overline{U}_1 + (\beta_1 l)^2 \overline{U}_2 = 0$$

$$\overline{U}_2'' + \left[(\gamma_2 l)^2 - (\alpha_2 l)^2\right]\overline{U}_1 + (\beta_2 l)^2 \overline{U}_2 = 0,$$

that together with the boundary conditions on the tips of piezoceramics layer allows to obtain electromechanical impedance of combined transducer.
Result of simulation of the electromechanical impedance is given in Figure 3.

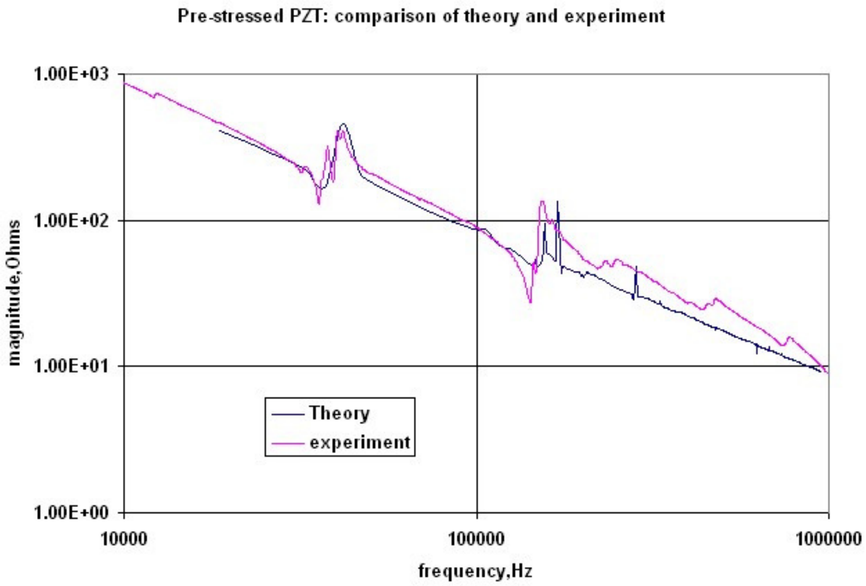

Figure 3. Comparison of the calculated and measured electromechanical impedance of pre-stressed transducer

The model of pre-stressed transducer allows obtaining many interesting feathers. First of all it is the important changing of spectrum of natural frequencies. The effect of elastic and geometrical parameters of a problem was analyzed.
The same approach can be used also for investigation of constrained effect of structural element to piezoceramics transducer.

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