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MODEL BASED IDENTIFICATION OF ACTIVE BEAM COMPOSITE STRUCTURE - APPLICATION MRAS ALGORITHM

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ABSTRACT

Parameter identification of the electromechanical system allows to match the knowledge about the state of the system and its properties. Execution of identification procedure during normal operation of the system without its stopping is a major problem of the carried out investigation. Implementation of such research requires measurement instrumentation saving transient data and processing them. Such system is expensive therefore some of measurement equipment we replace by software Model Based Identification methods. In the presented paper we characterize the possibility of applying these methods to identify active composite beam with embedded piezoelectric structure. Simulation results we present for Model Reference Adaptive System (MRAS). Applied adaptive algorithms satisfy Lyapunov stability. The selection of these algorithms take into account the condition of a short execution time compared to other methods. This condition is particularly important in future implementation in systems based on microprocessor Digital Signal Processor architecture (DSP).

THE AIM OF THE PARAMETER IDENTIFICATION OF ACTIVE COMPOSITE BEAM WITH EMBEDDED PIEZOELECTRIC STRUCTURE

Active composite structures are materials, whose internal design is the result of research actuators of high performance, lightweight, direct control and high-speed response. These are mainly: piezoelectric composites, nanoconductive particles, shape memory alloys and magneto-rheological elastomers structures [4]. Composite technology is getting popular in advanced constructions, especially in space and aircraft systems, biomedical actuators as well as high precision and responsible for safety reason systems. Special embedded structures practically do not influence on mechanical, thermal and geometrical properties and above all do not alter fundamental functionalities. Moreover, due to possibilities of electric, magnetic or thermal control, they may satisfy active functions of actuators or measuring segments, improving dynamic and static characteristics.

Planned application in aviation of the tested composite actuators impose specific requirements on these structures. Their application in skin plates of aerodynamic aircraft components demands of flat design, large deformation and work in closed loop system control. These requirements meet piezoelectric systems.

Unfortunately, piezoelectric composites are nonlinear systems. As confirmed in laboratory tests, piezoelectric elements are have unstable of parameters [6]. The internal parameters as e.g. resistance and capacity of the studied actuators varied depending on the level of voltage and frequency of power supply. These changes also concern mechanical parameters as e.g. stiffness and damping coefficients. Composite with embedded piezoelectric MFC structure changes their stiffness parameter determining the own frequency of the tested beam. Moreover, operation with significant deformations, may cause shift of the own frequency and nonlinear component in the motion equation (3).

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For these reasons application linear PID controllers or dumping filters to stabilize the work with predetermined stable parameters, however, has limited application. Due to the mentioned parameter changes of the mathematical model, nominal settings of filters and regulators give poor results, and sometimes even cause the generation of unexpected oscillations. For this reason, current identification of relevant parameters of the model or the use adaptive or nonlinear controllers are required.

Determination of parameters of the models typically are carried out during the specialized laboratory tests, when the bench can be equipped with a large number of measuring equipment. During normal operation of a craft, the possibility of measurements in transient states are usually very limited, and obtained measured data are insufficient to identify an object in real time. Therefore, implementation of real time identification methods, usually require application of Model Based Identification methods. These methods include mainly observer models, self-tuning systems and Model Reference Adaptive Systems.

1. OVERVIEW OF MODEL BASED IDENTIFICATION METHODS

Application of mathematical modeling to solve problems of nonlinear identification and control allows to limit the number of sensors. General scheme of parameter determination is based on a comparison of the measured variable with calculated variable, or comparison of two calculated variables provided, that they have been appointed on the basis of two different sets of equations [4]. Then, the result of his comparison is the input to certain adaptation block. This principle is presented in Fig.1.

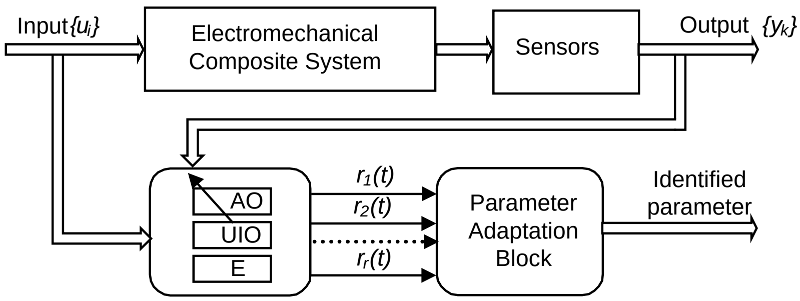

Fig.1 The overall structure of identification system, were: AO - is adaptive observer, UIO – unknown input observer, E – estimator or simulator of unknown input

Of the above methods, good results can be obtained using a computational observer structure introducing the unknown parameters $\Delta\mathbf{A}$ to the mathematical description of the state equation system (1), Fig.2.

$$\begin{cases} \dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu} + \Delta\mathbf{Ax} \\ \mathbf{y} = \mathbf{Cx} \end{cases} \tag{1}$$

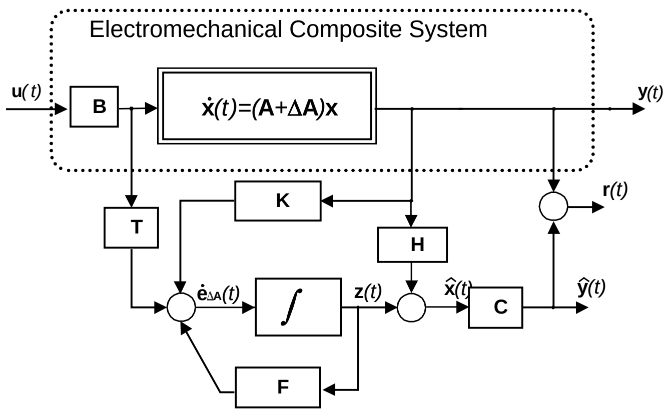

*Fig.2 Electromechanical system with Decoupling Observer, where **F** – state observer matrix, **T**, **H** – transposition matrices of input and output, **K** feedback matrix, **C** – output matrix, **z**(t), $\hat{\mathbf{x}}$(t) and $\hat{\mathbf{y}}$(t) – estimated variables.*

Properly selected transposition matrices of inputs and outputs, together with the state matrix **F** of the observer and feedback matrix **K**, allow to decouple estimated value of $\hat{\mathbf{y}}(\mathbf{t})$ from the change in the system are identified. This feature makes the UIO convenient tool for determining the unknown values of $\mathbf{\Delta A}$ in complex computational structures [5]. The condition, which should meet the observer matrices presents formula (2).

$$\dot{\mathbf{e}}_{\mathbf{\Delta A}}(t) = \mathbf{F}\,\mathbf{e}_{\mathbf{\Delta A}}(t) + \mathbf{T}\,\Delta\mathbf{A}\mathbf{x}(t) + (\mathbf{F}\,\mathbf{H} - \mathbf{K})\mathbf{y}(t) \quad (2)$$

An alternative solution is application a Self-Tuning Method (STM) or Model Reference Adaptive System (MRAS). Both methods have gained wide application in control systems and identification of parameters. Their main advantage, is simple structure resulting in less time-consuming calculations. Among the several varieties of this method, cited example of flowcharts (Fig.3) is beneficial especially for parameter identification.

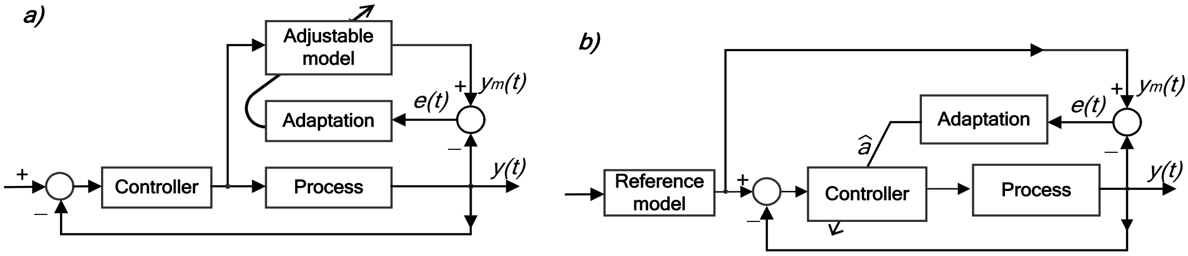

Fig.3 Model Reference Adaptive System. a) with adjustable model for parameter identification, b) with SetPoint generator

In the alternative solutions (Fig.3), MRAS adaptive models are used directly to control adaptation parameters and are rarely used as SetPoint generators with adaptive controllers [1]. In systems designed to identify the parameters, adaptation algorithm adjust parameters of reference model due to the ***e(t)*** output error. Received estimated parameters $\hat{a}$ may be applied in diagnostic systems as well as in control systems.

2. REFERENCE MODEL AND THE CHOICE OF IDENTIFICATION METHODS

The composite beam with embedded Macro Fiber Composite (MFC) inside its structure has been tested at laboratory stand. During the tests, this actuator was used for vibration damping and positional adjustment.

During operation, especially at large deformations, the mathematical model of the beam must take into account the nonlinear units. A simple one-dimension model, the equation can be represented as formula (3).

$$\ddot{y} + 2\mu\omega\dot{y} + \omega^2 y + \beta y^3 - \delta\left(y\dot{y}^2 + y^2\ddot{y}\right) = f\cos(\Omega t) \quad (3)$$

where: y – beam deflection,
ω – own frequency,
μ – damping coefficient,
β, δ – factors determining the intensity of the nonlinearity,
f – forcing amplitude,
Ω - frequency of the external force.

The existence of nonlinear units by factors β and δ, causes a shift of the natural frequency or the total value of the damping force. These changes have adverse impact on the effectiveness of the work the piezoelectric actuator, causing the upset the control system. Therefore, there is a need for continuous monitoring, especially monitoring of natural frequencies of the beam.

In the considered system assumed, that the strain gauge signal is available. Resistive nature of this sensor can determine the level of strain and rate of change with any significant delay effect. The reference model for system control as well as for parameter adjustment does not take into account β and δ factors of non-linear components. These nonlinearities we take account adding new variables $\Delta\omega$ and $\Delta\mu$. These addition update parameters (3a) are trending to the meet with current values. This interpretation allows to obtain higher processing speed, by eliminating time-consuming procedures of multiplication and exponentiation.

$$\begin{bmatrix} \dot{y} \\ \ddot{y} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -(\omega+\Delta\omega)^2 & -2(\mu+\Delta\mu)\cdot(\omega+\Delta\omega) \end{bmatrix} \begin{bmatrix} y \\ \dot{y} \end{bmatrix} + \begin{bmatrix} 0 \\ f\cos(\Omega t) \end{bmatrix} \tag{3a}$$

Verifying conditions of the decoupling observer Fig.2, and regarding the changes of parameters $\Delta\omega$ and $\Delta\mu$, it is easy to see that the required matrix transposition **T** (Fig. 2) does not exist [5]. For that reason canceled the identification of parameters with decoupled observers. The attention has been drawn to the identification based on the Model Reference Adaptive Systems (MRAS) shown in Fig. 3.

Real time identification requires the use of high-speed data processing algorithms that can be mplemented in a microprocessor system. Considered two methods, first using an algorithm of Model Identification Techniques (MIT) and second adjusting algorithm satisfying Lyapunov stability condition.

The MIT rule has historically been the first adjustment mechanism used in model reference adaptive systems [2]. Its application give good results during adjusting nonlinear system parameters. The main idea is based upon the reduction of the loss function $J(\theta,t)$ (4) .

$$\begin{gathered} J(\theta,t) = \frac{1}{2} e^2(\theta,t) \\ e(\theta,t) = y(t) - y_m(\theta,t) \end{gathered} \tag{4}$$

where $\boldsymbol{\theta}$ determines the differences of model parameters against the reference model and $\boldsymbol{e(\theta,t)}$ is a difference in real output $\boldsymbol{y}$ and the reference model $\boldsymbol{y_m}$. Identification method is based on the search for extremum of the loss function with respect to variable $\boldsymbol{\theta}$, according to formula (5).

$$\dot{\theta} = -\gamma \, \nabla J(\theta) = -\gamma e(\theta)\, \nabla e(\theta) \tag{5}$$

where

$$\nabla e(\theta) = \begin{bmatrix} \dfrac{\partial e}{\partial \theta_1} & \dfrac{\partial e}{\partial \theta_2} \cdots & \dfrac{\partial e}{\partial \theta_r} \end{bmatrix}^T$$

Considering that the real model $\boldsymbol{y(t)}$ does not depend on $\boldsymbol{\theta}$, we can rewrite MIT rule in the following form

$$\dot{\theta} = -\gamma e(\theta)\, \nabla y_m(\theta) \tag{6}$$

An alternative method of adaptation is the choice of the controller according to the Lyapunov criterion, searching for asymptotic stability conditions [2]. The used formula defining the criterion is created by equations (7, 8)

$$V(x) = \int_0^e u(y)dy + \frac{e^2}{2} \tag{7}$$

where $\boldsymbol{V(y)}$ is interpreted as a Lyapunov function of the energy, corresponding output of the test. This function should be positively determined, and its derivative with respect to time should be less than zero.

$$\dot{V}(e) = \frac{\partial V}{\partial t} + \frac{\partial V}{\partial e}\dot{e} \le 0 \qquad and \qquad \dot{e} = f(y,t,u) \tag{8}$$

Using the set of rules, derived the stability of adaptive MRAS system. Comparing the number of necessary operations, for further study data processing satisfying the Lyapunov condition has been selected, as more faster method in microprocessor DSP system. Chosen method should ensure compliance with stringent requirements in time.

3. SIMULATION AND LABORATORY TESTS

Simulation studies were conducted as pre-testing phase of research to prepare and verify numerical procedures for DSP laboratory stand. Therefore, one of the selection criteria was obtaining a high-speed processing. For this reason, a reference model has been written in the form of linear second order differential equation. Actual model, which was the equivalent of the process presented in Fig.3, was written in the form of nonlinear differential equations (3).

The aim of the executed tests was to examine the level to which it is possible to determine the change in frequency of the working beam.

Among the many results, as the representative to submit in the article, selected cases where the own frequency of the reference model differs significantly from the frequency of real process model (Fig.4) and when this difference is small (Fig.5). In addition, studies were carried out for different degrees of non-linearity of the process, when the coefficients δ and β in equation (3) are close to zero (Fig.4 a, b) or are equal to unity (Fig.4 c, d and Fig.5)

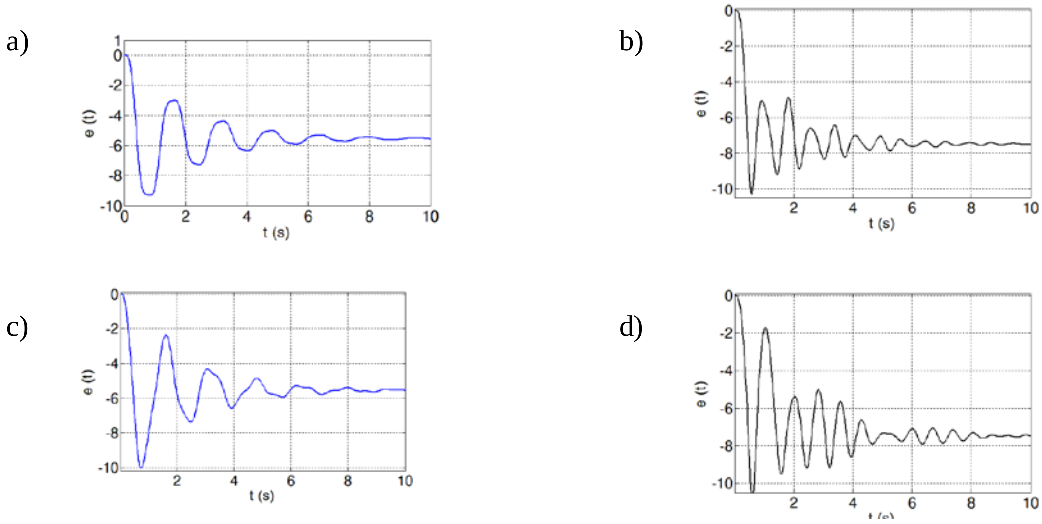

Fig. 4 The errors e(t) were obtained for significantly different own frequencies of the reference model and the process model. The a) and b) results received for the linear model, c) and d) for non-linear. In addition, the plots a) and c) correspond to open-loop adaptation, while the plots b) and d) correspond to the structure of the closed-loop adaptation with proportional controller.

The results indicate the good convergence of the simulation. Unfortunately, there is no linear relationship between the corresponding output and the difference in own frequencies of its reference model and process. These relationship also depend on the current value of the frequency of its own process. It could be therefore formulated as a three-dimensional function .

For the closed-loop system with the adaptive loop and proportional controller, the fixed off-set error is still different from zero. The increase of amplifier's coefficient of the controller results in accelerating the *e(t)* transition state and error's amplitude. Replacement P controller by PI changes the qualitative results. The proper choice of integration and amplifier constants, accelerate operation of the adaptive system and minimize the off-set error.

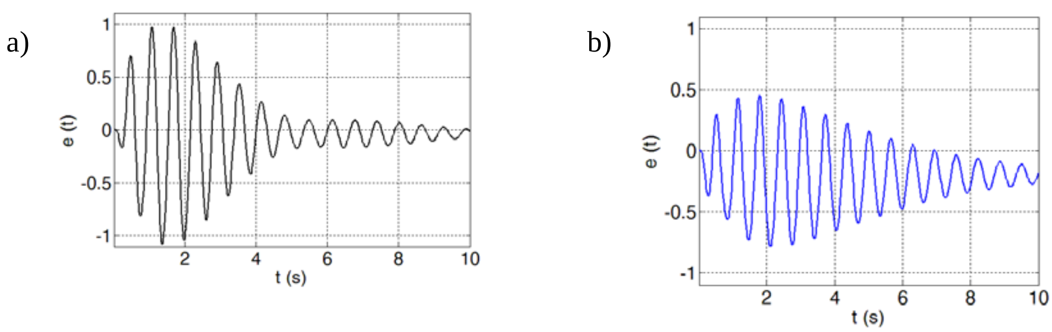

Fig. 5.The error from the close-loop adaptation system, when the frequency difference of the process and its reference model differs by the value a) $(\omega_p-\omega_r)/\omega_p$=2%, b) $(\omega_p-\omega_r)/\omega_p$=10%

An interesting situation occurs in a transient states, if the process frequency and frequency of the reference model is not too far away. This phenomenon may cause beat vibrations occurrence which may generate an initial increase in amplitude of the transient signal (Fig.5, b).

Besides, simulations of step response tests were carried out also for harmonic inputs. Their interpretation requires a slightly different presentation of results. Due to the convergence of *e(t)* output error to zero, regardless of differences in the own frequencies, direct estimation of the frequency difference ω_p-ω_r (process frequency, and reference model frequency) is relevant. Simulated models, however, require further optimization of the time, which will be verified at laboratory tests.

4. RESULTS AND CONCLUSIONS

Obtained results indicate the identification possibility of the own frequency of the beam during normal operation. For step inputs, the convergence and control time depend on the parameters of adaptation algorithm. Ill-defined controls cause increasing vibrations of the observed variable. To ensure zero error in steady state, simple and effective solution gives proportional corrector or properly selected proportional integral corrector.

The presented stage of the research is preliminary in nature, preparing procedures for the laboratory tests. The measurement data from the real process will certainly differ from the applied at the simulation process model. These differences, however, will not affect the performance of the adaptation algorithm.

Sharp temporary requirements decided about the selection of a linear dynamic model as the reference model. This form of the model should provide adequately fast response of microprocessor system. The obtained in results give promising effects both for the purposes of identification and regulation.

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