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Damage Dynamics of Engineering Systems Under Varying Operational Conditions: Numerical Analysis and Modelling

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Abstract: The paper is devoted to development and application of an effective computational approach to analysis, modelling and prediction of a chaotic behaviour of dynamic properties of vibrating structures. There are listed data of analysis, modelling, processing chaotic time series, which represent the structural dynamic properties of engineering structures. The computational approach includes a combined set of non-linear analysis and chaos theory methods such as an autocorrelation function and correlation integral approach, average mutual information, surrogate data, false nearest neighbours algorithms, the Lyapunov's exponents (LE), Kolmogorov entropy analysis, spectral methods, prediction (predicted trajectories, neural network etc) algorithms (in versions [1-4]). The results of numerical studying the topological & dynamical invariants of the time series for the experimental cantilever beam [5] (forcing and environmental conditions are imitated by the damaged structure, the variable temperature and availability of the pink-noise force) are listed. Application of the approach to monitoring the health (security) of a nuclear reactor vessel is presented.

Keywords: numerical modelling, engineering structures, time series, chaos

1. Introduction. Universal Chaos-Geometric Approach to Dynamics of Geosystems

An analysis, identification and further prediction of the presence of damages (cracks), which above a certain level may present a serious threat to their performance of the technical structures, remains challenging problem in their monitoring engineering structures. The correct treatment requires extensive use of measurement and advanced mathematical and computational tools of processing. Usually change of structural properties due to operational and other effects (temperature, moisture, pressure etc) allows to detect an existence, location and size of damages. Changing these conditions may cause significant changes in their properties and result in the damage detection algorithms to false decisions. The standard way is using so called structural health monitoring methods that allow early identification and localization of damages (e.g. [1]). Usually change of dynamic properties due to environmental, operational and other effects allows to determine the existence, location and size of damages.

This paper goes on our work on studying and advancing an effective computational approach to analysis and prediction of a chaotic behaviour of dynamic properties of the vibrating structures. There are listed the results of analysis, modelling and processing the corresponding chaotic time series, which represent the structural dynamic properties of the engineering structures. The computational approach applied includes a combined set of non-linear analysis and chaos theory methods such as an autocorrelation function method, correlation integral approach, average mutual information, surrogate data, false nearest neighbours algorithms, LE and Kolmogorov entropy analysis, spectral methods and prediction (predicted trajectories, neural network etc) algorithms (e.g. [1-4]).

2. Results and Discussion

As illustration, there are listed data of the complete numerical investigation of a chaotic elements in time series for the simulated 3DOF system and an experimental cantilever beam. The corresponding cantilevel beam time domain response series data are taken from [5], where there are listed the detailed data of experimental studying a cantilever beam excited by white and pink noise forces. As example, in Table 1 the results of computational reconstruction of the attractors (the correlation dimension (d_2), embedding dimension (d_E), the first two LE (λ_1,λ_2), the Kaplan-Yorke dimension (d_L), as well as the Kolmogorov entropy (K_{entr}), and average limit of predictability (Pr_{max}) are listed.

Table 1. The correlation dimension (d_2), embedding dimension (d_E), first two LE (λ_1,λ_2), Kaplan-Yorke dimension (d_L), and the Kolmogorov entropy, average limit of predictability (Pr_{max}, hours)

d_2	d_E	λ_1	λ_2	d_L	K_{entr}	Pr_{max}
5.45	6	0.0197	0.0061	3,98	0.026	39

These data are related to a case of the damaged structure, the variable temperature and availability of the pink-noise force. System is generally considered to exhibit chaotic elements. The dimension of an attractor is defined as embedding dimension, in which the number of false nearest neighbouring points is less than 3%. The presence of 2 positive λ_i suggests the conclusion above regarding presence of a chaos. The non-linear methods [2-4] are used for the temporal evolution prediction. Even though the simple procedure is used to construct the non-linear model, the results are quite satisfactory.

3. Concluding Remarks

An universal chaos-geometric approach is appled to analysis, modelling and forecasting a chaotic behaviour of dynamic properties of the engineereing structures. The advanced numerical data on the topological and dynamical invariants of the time series for the experimental cantilever beam [4] (the forcing and environmental conditions are imitated by the damaged structure, the variable temperature and availability of the pink-noise force) are listed. The presented chaos-geometric approach in combination with the blind source separation methods has been proposed as a powerful signal processing method capable of monitoring health of large class of engineering structures, in particular, nuclear reactor vessel safety.

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