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Simulation of Nonlinear Characteristic of Aileron Attachment on Aeroelastic Demonstrator Using Active Electromagnetic Spring Concept

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Abstract: The paper is focused on the design and development of the system simulating nonlinear attachment of the aileron actuation on the aeroelastic demonstrator. The system is based on the concept of the digitally controlled additional stiffness, activated by the real time control law system controlling the required ratio of the force and deformation. The solution is based on the electromagnetic exciter. The nonlinear force is simulated by means of the system of an exciter and the deformation sensor. The active control system is independent of the excitation system. It adds the force ensuring the required characteristics and it allows to simulate the additional stiffness, damping or mass. Doing this, it is possible to adjust the selected vibration mode by controlling the force and obtain the required nonlinear characteristics. In the second order, there is also a constant influence of the exciter mass, stiffness and damping. The simulation of the linear, quadratic and cubic additional stiffness were verified.

Introduction

The intention for the nonlinear aeroelastic demonstrator development arose in connection with the research of methods for ground vibration testing including nonlinearities. Modal characteristics of aircraft structures are always more or less nonlinear. Provided the nonlinear effect is small, the structure response to the harmonic excitation is quasi-harmonic and can be expressed by the equation including amplitude dependent damping and stiffness term. Nonlinear stiffness causes the asymmetric resonance peak, whereas nonlinear damping influences amplitude-phase curve.

A typical nonlinear behavior of riveted aircraft structure is decreasing of a natural frequency and approaching the asymptotic value with increase of the amplitude. This is caused by the contact surfaces of rivets (or bolts) and the structure. The effect is small and the structure response can be expressed by the linear model. Much more complicated problems may be caused by the large nonlinearities caused by dry friction or backlash inside bearings or pin joints, e.g., in the control surfaces actuation systems. The natural frequency may vary significantly (by 10 - 20%) and the structure response must be described by fully nonlinear equation [1]. This is a typical behavior of the control surface flapping modes. The identification of modal parameters is complicated and the specific methods [2] for the nonlinear parameters identification must be employed. The research of such appropriate processes and methods is necessary. The aeroelastic demonstrator "NOLWING" [3], [4] was developed as a research test bed for the research of the methods for the nonlinear parameters identification.

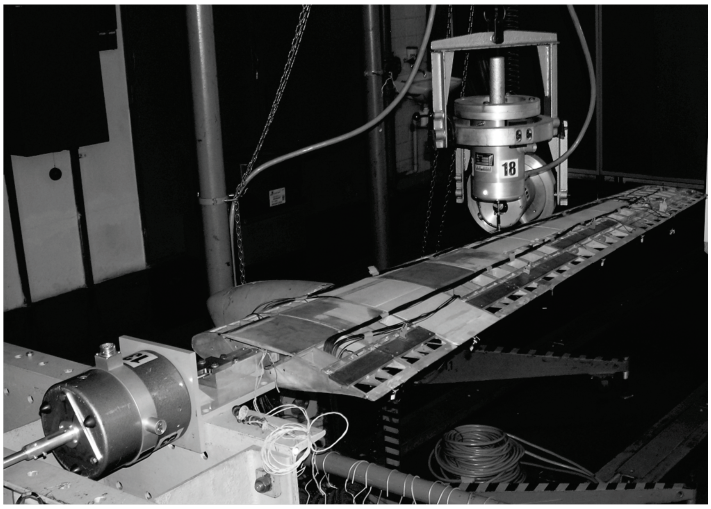
Fig. 1: NOLWING Aeroelastic Research Demonstrator

Active electromagnetic spring concept for nonlinear aileron actuation

This concept is based on the active control of dynamic characteristics of the vibrating system by means of force generated by an electromagnetic shaker. The general control system may be capable of adding any type of force to the system, namely inertia, damping or elastic force. Our work was particularly aimed at the simulation of nonlinear stiffness of the aileron actuation system.

The regulator software is based on the LabVIEW Real-Time environment. The system also includes an independent generator of excitation signal (static force, impulse, harmonic constant frequency, harmonic frequency sweep) which was exploited for the demonstrator testing. The practical application of discrete-time regulation is based on the 3rd order (cubic) polynomial approximation of the regulation force function. It allows simulating the typical aileron stiffness, viscous damping and additional mass characteristics. Another variant facilitates the inclusion of freeplay. Fig. 2 shows the amplitude - frequency curves of the aileron flapping mode without and with active control. The former (Fig. 2a) can be considered as a symmetric behavior while the latter (Fig. 2b) shows the nonlinear effect. The parameter of active control is represented by the cubic coefficient (coefficient "a").

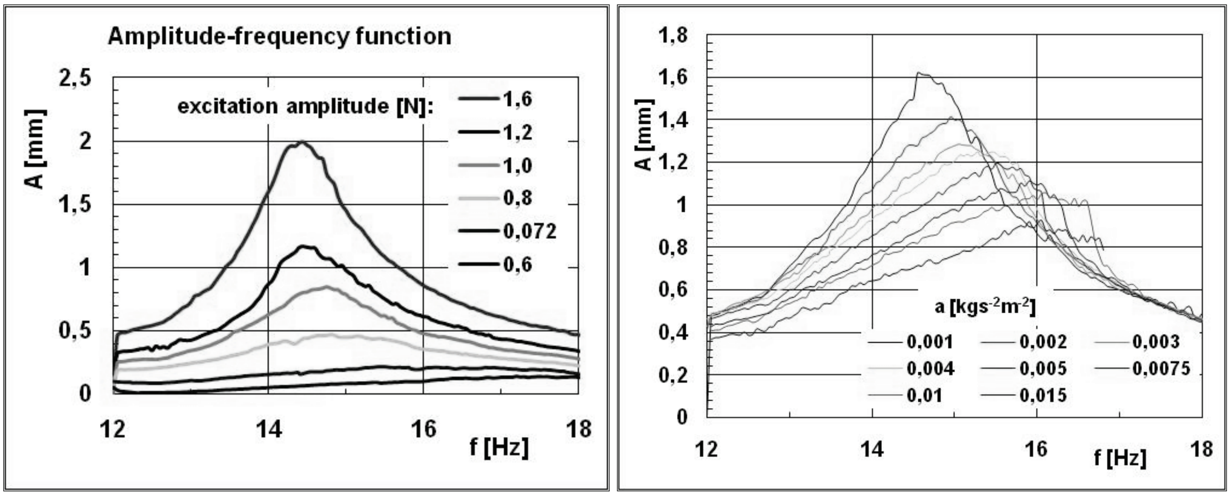

Fig. 2: Amplitude - frequency curves without (a) and with (b) active stiffness regulation

A negative linear coefficient may be used to eliminate the shaker stiffness. The additional mass equation may be used to eliminate the shaker mass effect. The system may be also stabilized by means of a damping force introduced into the additional damping equation.

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