AUTOMATIC PHASE RESONANCE TESTING OF AIRBUS EXWING AIRCRAFT FOR FLUTTER COMPUTATION UPDATING

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ABSTRACT

An automatic phase resonance method is developed to facilitate ground vibration test (GVT) of aircraft structures. This technique builds on the well-known phase resonance method (PRM), and improves on the robustness and testing duration. As an extension of the phase-locked loop method (PLL), which is a recent technique in nonlinear structure identification, it is well adapted to complex systems. The extended algorithm exploits the complex power to minimize the mean phase deviation (MPD) of the response signals. Modal property changes with respect to energy level are robustly tracked with minimal effort. It is successfully implemented as a sub-routine of the GVT of the new Airbus extra performance wing (eXwing) demonstrator aircraft.

INTRODUCTION

Flutter computational models are calibrated with modal parameters identified during GVT. In the development of an aircraft, a GVT campaign is required to identify its modal properties. It is recommended to describe their evolution with respect to different energy levels. Since the operating regime of an aircraft can be in the nonlinear domain, this influences the modal response. Tracking these changes is manually challenging and time consuming. To address this challenge, an automatic phase resonance method which is based on the phase-locked loop (PLL) method [1] is developed.

PLL tracks the mode evolution of a structure by controlling the phase lag of a reference point response signal to the excitation signal. However, the method is inherently limited to single-input single-output (SISO) control. For GVT applications, PLL must be extended to accommodate large number of inputs and outputs. An extended algorithm to handle such a scenario is presented herein. It is successfully demonstrated during the GVT of the Airbus eXwing aircraft, and results are used to update individual modes of the flutter computational model.

EXPERIMENTAL SET-UP AND METHOD

The Airbus eXwing aircraft is characterized by its foldable wing tip (FWT) supported by a semi-aeroelastic hinge (SAH). The eXwing demonstrator is equipped with novel technologies to improve flight performance and reduce carbon emissions. It is tested at different configurations. Results are herein presented for the 30° FWT latched configuration. It is instrumented with 439 accelerometers, and force measurement sensors. The aircraft is suspended by three air suspension systems to emulate a free-free boundary condition.

The PLL is adapted to monitor the multi-point excitation configuration. This is realized by two different strategies aimed at minimizing the MPD across all input points. One approach is to project the signals onto the linear modal space, and then controlling the phase lag of the modal response. This solution may be erroneous if the nonlinearity is strong or the mode shape deviates significantly. A more robust solution is to track the phase of the complex power whose imaginary part should vanish at resonance [2]. It is valid for nonlinear systems. Given the vector of complex amplitudes of the response and excitation forces, $\widehat{\boldsymbol{q}}$ and $\widehat{\boldsymbol{f}}$, respectively, the complex power is defined as,

$$P = (i\omega\widehat{\boldsymbol{q}})^H\widehat{\boldsymbol{f}}, \qquad (1)$$

where i is the complex symbol and ω is the frequency in radians. At resonance, the phase of the complex power is 0° with respect to the excitation signals. The PLL algorithm is thus, modified to accept this parameter as the control variable.

Three closely separated modes, namely: the 4N wing bending, engine heave anti-symmetric and symmetric modes, are of interest. Appropriate isolation of these three modes requires appropriate force vectors provided by at least four shakers distributed around the aircraft [3]. Specifically, two Prodera 500 N shakers on the wing box (one each side) and two Prodera 500 N shakers on the HTPs (one on each side), all in the vertical Z-positive direction are used.

RESULTS

Figure 1. shows the frequency and damping evolutions of the 4N wing bending mode. The frequency decays exponentially while the damping ratio increases with increase in excitation energy. The quality of the mode isolation is assessed by the Mode Indicator Function (MIF) with 1 signifying perfect mode isolation. According to the MIF, the algorithm successfully isolated the mode at the different energy levels. However, the MIF does not quantify the effect of nonlinearity. Other isolation criteria will be presented to better assess the nonlinear effects. The isolation of the Engine heave anti-symmetric and symmetric modes will also be presented to demonstrate the robustness of the method in tracking the evolution of each mode.

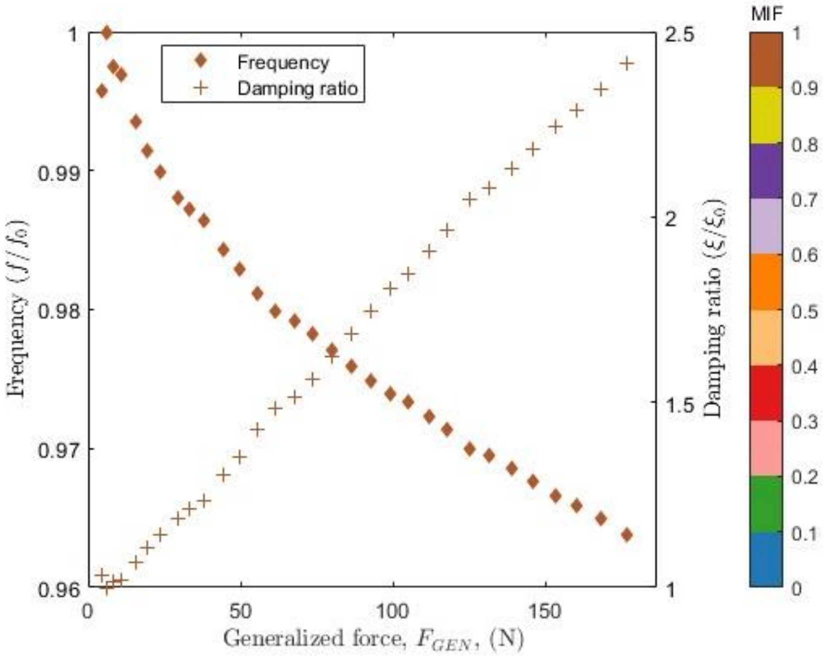

Figure 1: Frequency and damping evolution of the 4N wing bending mode. Values are normalized by their respective linear quantities $(\square_0)$.

CONCLUSION

An automatic phase resonance testing algorithm has been implemented during the GVT of the Airbus eXwing aircraft. The algorithm permits to track mode property evolution with increasing energy, and allows more amplitude levels to be probed in a very short duration compared to conventional phase resonance method. By exploiting the complex power, the algorithm extends the capability of PLL to the identification of multi-input multi-output systems (MIMO) such as aircraft structures.

References

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