Helicopter Post-critical Ground Resonance Oscillation Amplitude Using Multiple Input Describing Function

Giuseppe Quaranta

Department of Aerospace Science and Technology, Politecnico di Milano, Milano, Italy

Abstract. The paper presents the application of the quasi-linearization technique to investigate the effect of nonlinearities on the ground resonance stability of a helicopter. A rigorous derivation of the the governing equations is presented showing that the combination of rotating and non rotating pats leads to the need to consider, even in the simplest cases, more than one harmonics in input in the components that are mounted on the rotor. Using the multiple input describing function approach, it will be shown how it is possible to investigate the cases when multiple harmonics are injected into a nonlinear component.

Introduction

Helicopter rotors are subject to potentially destructive instabilities due to the interactions between the main rotor dynamics and its flexible support, usually denominated ground resonance. The basics of the phenomenon are well known and understood, see [1, 4]. However, it still not so uncommon to read accident reports related to ground resonance, like what contained in the final Report No. 2122 by the Swiss Accident Investigation Board SAIB concerning the accident involving the Agusta A109K2 helicopter on 23 June 2008 [1]. It involves the coupling of the blade in-plane motion with the underlying airframe motion. This problem usually affects helicopters that mount an articulated rotor when on the ground, sitting on the landing gear. To solve the problem, usually lead-lag damping needs to be added on rotor blades. The sizing of this damping element is always the result of a trade-off study to harmonize the requirement of high damping for stability with the need to reduce the loads transmitted to the hub by the blades. Linear analysis methods are able to predict the critical stability boundaries, and so they can be used to design the lag dampers that must be applied to rotor blades.

However, modern helicopters rarely exhibit destructive resonances, but they may be subject to limit cycle oscillations (LCO), see [8, 7]. To predict these LCO conditions it is necessary to consider the contribution of nonlinearities. The identification of LCO conditions can be performed by using the Describing Function approach presented in Ref. [2], which allows to keep into account multiple nonlinearities in the same model. The method of [2] is here extended to cope with the peculiar aspects required when the model of the system includes at the same time a component in a fixed reference frame, the airframe, and a set of rotating bodies such as the blades. It will be shown that this leads naturally to the necessity to consider Multiple Input DF (MIDF) approaches.

Multiple Input Describing Function for Rotors

Starting hypothesis says that the response of the flexible support is dominated by a single harmonic, it is possible to show that the lead-lag dampers mounted on rotor blades, so in the rotating reference frame, are in general excited by two harmonics, the regressive $\omega - \Omega$ and the progressive $\omega + \Omega$ modes, where Ω is the angular velocity of the rotor. The application of the DF approach to the ground resonance problem is not new (see [8]), however here for the first time the problem is approached using the MIDF that allows to address also the problem of LCO that arise when cyclic commands are applied to the rotor, a case where a the multi-frequency nature of the damper input signal can not be neglected. The methodology used here for the solution of nonlinear stability problems is described in Ref.[5]. Considering an hinged rotor of b blades mounted on a flexible support, it is possible to obtain the basic Ground Resonance system of equations by applying to the rotating parts a transformation of the rotating coordinates into multi-blade coordinates, describing the rotor motion in the inertial reference frame, as introduced by Coleman [1].

This transformation allows to switch from a periodic system of equations into a time invariant system of equations. It is useful to understand what happens when we try to apply this coordinate transformation to the nonlinear damper models. It has been shown in Ref. [6] that in general for each blade $2N + 1$ MIDF must be computed each one that depend on $4N + 1$ parameters However, of all the b multi-blade dofs only the first two cyclic components are considered for stability analysis when linear models are considered since the other lag motions, either collective or reactionless, do not couple with hub motions.

The very simple ground resonance example consisting of the single rotor helicopter suggested by Hammond in the classical paper [3] has been chosen to present the potential of the synthesis approach proposed in the previous sections. In this case the simple four degrees of freedom model can adequately represent the phenomenon.

[1] `https://www.sust.admin.ch/inhalte/AV-berichte/2122_e.pdf`

With the chosen parameters the real part of the four eingenvalues of the linearized model is shown in figure 1 it is possible to see that the system is unstable for $0.829 < \Omega < 1.14$. Modeling the airframe support along

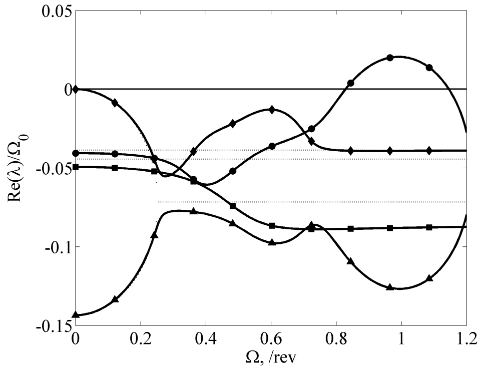

Figure 1: Real part of the eigenvalues of the linerized model.

the x and y direction as a two nonlinear dampers with a force $F = \sigma\dot{x}|\dot{x}|$ the following LCO amplitudes are obtained, first for the symmetric case with equal values of $\sigma_x = \sigma_y = 5000$, and second for a non symmetric case where $\sigma_x = 10\sigma_y$, see figure 2.

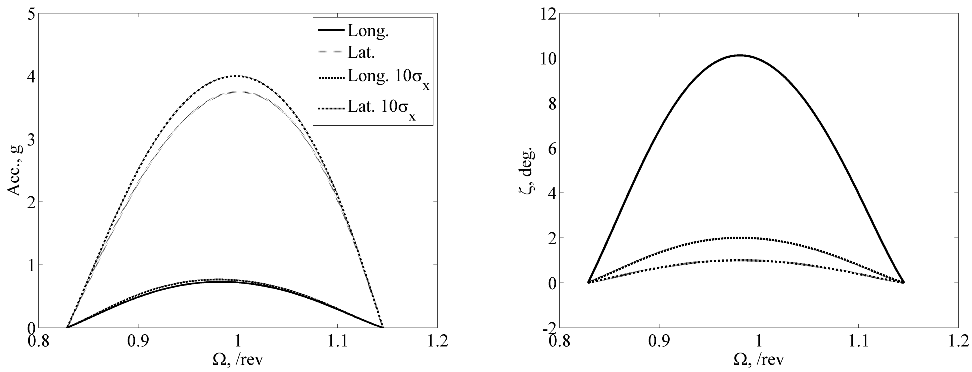

Figure 2: LCO obtained with a unsaturated dampers on the airframe: on the left airframe accelerations lateral and longitudinal; on the right blade lead-lag rotation.

Conclusions

The paper presented the application of the Multiple Input Describing Function approach to investigate the effect of nonlinear components on the ground resonance stability. It has been shown how a rigorous analysis must consider even in the simplest case more than one harmonics in input in the components that are mounted on the rotor.

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