ISROMAC 2017
International Symposium on Transport Phenomena and Dynamics of Rotating Machinery
Maui, Hawaii
December 16-21, 2017

[Extended Abstract]

Energy localisation in periodic structures: application to centrifugal pendulum vibration absorber

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Introduction

In this work we study the non-linear dynamic of centrifugal pendulum vibration absorbers (CPVA). Those components are often found in rotating machinery to suppress undesired rotational vibrations in the main shaft. For example, in the automotive industry they are used to suppress engine order vibration at the entrance of a gearbox [1]. They can also be used to reduce translational vibration of bladed rotor in helicopters [2]. This kind of absorber is very convenient because, due to centrifugal force, the vibration absorbers stay tuned to a particular engine order, even while ramping up.

However, due to the different choices for the trajectories of the pendulum and due to the large amplitude of motion, the system is non-linear and the resonance frequencies depend on the amplitude. The behaviour can be hardening or softening depending on the choice of the trajectory for the pendulums [1]. Such non-linearity results in a completely new set of phenomenon as compared to the linear case. In particular, it can happen that the energy localizes to a particular subsystem, leaving the others virtually motionless [3, 4]. The prediction of such states of vibration, and their stability, is of particular importance because they can lead to inefficient behaviour for the CPVA and/or unforeseen stress levels. Such has already been done unsing analytical technic such as the (complex) averaging method [4].

Here, unlike previous work, the computations are realized in a fully numerical framework in the frequency domain. The Harmonic Balance Method (HBM) and the Asymptotic Numeric Method (ANM) will be used for the continuation of periodic solutions of free (Nonlinear Normal Modes, NNM) and/or forced systems (forced responce). Moreover the stability and bifurcation analysis is performed using Floquet's theory. Everything is linked together and controlled with the GUI of the MANLAB tool developed under the direction of B.Cochelin [5].

1. Methods

We consider a structure composed of N identical pendulums attached on a main rotating structure which is excited by a periodic torque. The rotating motion of the main structure is measured by the angle θ and the pendulum motions are measured by their non-dimensional curvilinear abscissa $s_i,\ 1 \leq i \leq N$.

Following the devellopement in [4] the angular variable θ is eliminated from the $N+1$ equations of motion, leading to a set of N differential equations. Moreover, the trajectory of the pendulums is developed in order to obtain a polynomial (cubic) expression for the non-linear forces. The resulting set of simplified equations (in non-dimensional form) is given by the following (see e.g. [4]):

$$\ddot{s}_i + 2\xi \dot{s}_i + (1+\mu)s_i + \gamma s_i^3 + \mu \sum_{k \neq i} s_k = \mu f \cos(nt), \quad 1 \leq i \leq N \tag{1}$$

Where μ is the inertia ratio between the main structure and the pendulums, ξ is the damping coefficient, f is the normalised excitation level and $\gamma = \pm 1$ is the sign of the non-linearity (depending on the choice of trajectory for the pendulums).

2. Results

Two kind of studies are conducted on Eq.(1). First, we consider only two pendulum and we study the effect of the inertia ratio μ on the bifurcation diagram of the free and forced response. In a second part, we study the effect of adding more pendulums to the main structure. In both case, we conduct a stability/bifurcation analysis of the free and forced response. Finally results of the simplified equation (1) are compared with the results of the full equation (no development of the trajectories and no elimination of θ).

Typical results for the free response of a system with two pendulums are given on Fig.1 where it can be seen that the in-phase solution of a system with hardening pendulums bifurcates to a localized solution that can be stable in some frequency range.

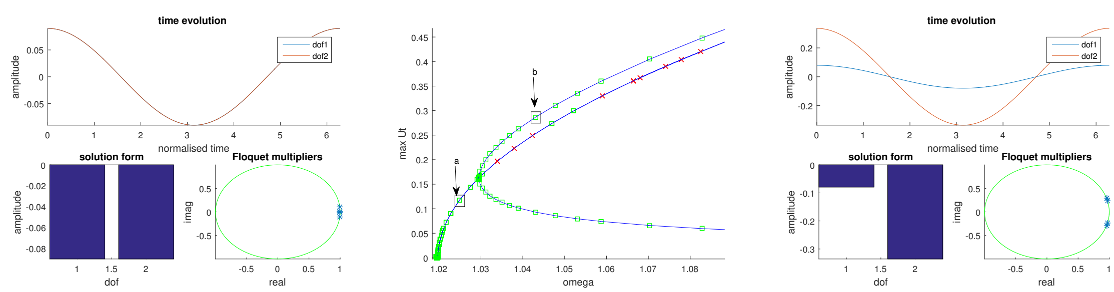

Figure 1. Typical results for the NNM of a two pendulum system. Middle: amplitude vs frequency (□: stable, ×: unstable). Left and Right: example of (stable) homogeneous and (stable) localised solution

References

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