



Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Tuning transient dynamics by induced modal interaction in mechatronic systems[☆]

Fadi Dohnal

Department of Biomedical Computer Science and Mechatronics, Division for Mechatronics Lienz, Private University for Health Sciences, Medical Informatics and Technology (UMIT), Lienz, 9900, Austria

ARTICLE INFO

Article history:

Received 1 September 2015

Revised 17 March 2017

Accepted 27 May 2017

Available online xxx

Keywords:

Semi-active vibration control

Modal energy transfer

Parametric anti-resonance

ABSTRACT

Introducing time-periodicity in one or more system parameters may lead, in general, to a dangerous and well-known parametric resonance. In contrast to such a resonance, a properly tuned time-periodicity is capable of transferring energy between vibration modes. Time-periodicity in combination with system damping is capable of efficiently extracting vibrational energy from the system and of amplifying the existing damping affecting transient vibrations. Operating the system at such a specific time-periodicity, the system is tuned at a parametric anti-resonance. The present contribution outlines the basic physical interpretation of this concept and summarises the experimental validation for different mechatronic systems. Starting with a theoretical performance measure, all experiments related to this concept are compared qualitatively and the two most successful implementations are discussed in more detail.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Transient vibrations in mechanical systems are a common problem in engineering, see e.g. [1–3]. All concepts to tackle this problem can be classified as passive, semi-active, active or hybrid means. For passive concepts, the system parameters are designed once and do not change during operation of the vibrating structure. Design parameters for handling transient vibrations are damping as well as mass and stiffness parameters. One class of passive concepts is re-designing the mass and stiffness distribution in order to shift the natural frequencies outside from the frequency range of operation or to tune corresponding vibration modes to acceptable deformation shapes. Once the main system design is set, the last passive possibility to affect the transient vibration is the choice of a proper damping. Semi-active concepts summarise concepts that change system parameters actively. For example, utilising electro- or magnetorheological fluids, the force transferred between the fluid and the system depends mainly on the effective damping which is set by an external electric or magnetic field. Active concepts incorporate real-time control of the force acting on the system directly. Finally, hybrid concepts combine features of all concepts. This contribution discusses a semi-active concept, the parametric vibration absorption or parametric anti-resonance.

In contrast to the classic passive dynamic vibration absorber, the parametric vibration absorption does not need an additional subsystem consisting of mass, stiffness and damping elements. Knowing only the natural frequencies of the system of focus, a parametric vibration absorption is implemented by varying one or more system parameters periodically in time. Tuned properly, a parametric anti-resonance is created which couples the vibration modes of the underlying Hamiltonian system and enables an energy transfer between a lightly and a strongly damped vibration mode. This targeted energy transfer has been observed only for strongly nonlinear vibration absorbers outlined in [4] so far. However, parametric vibration absorption does not need nonlinearity and works for purely linear systems, too.

Systems of differential equations with time-periodic coefficients, also termed parametrically excited systems, have been the focus of research since many decades. Parametrically excited vibrations occur if one or more parameters of the equations of motion are not constant but are described explicitly by a function of time; periodic and independent of the system motion. Classic examples are the pendulum with periodically varying length or periodically moving pivot point leading to the famous Mathieu, Hill or Meissner equation. Parametrically excited systems and structures have been studied extensively in the past because of the interesting phenomena that occur in such systems. A parametrically excited system may exhibit a destabilising parametric resonance if at least one system parameter is varied close to a parametric excitation frequency (see e.g. [5–7])

$$\nu^{kl,n} = \frac{|\omega_k \mp \omega_l|}{n}, \quad k, l, n = 1, 2, \dots \quad (1)$$

[☆] This paper is dedicated to Aleš Tondl, the pioneer of parametric anti-resonance. The content of this paper was presented as a keynote during the 3rd International Conference MECHATRONICS – Ideas for Industrial Applications in Gdańsk, Poland, May 11–13, 2015.

E-mail address: fadi.dohnal@umit.at

<http://dx.doi.org/10.1016/j.mechatronics.2017.05.010>

0957-4158/© 2017 Elsevier Ltd. All rights reserved.

Herein ω_k and ω_l denote the k -th and l -th angular frequency of the underlying undamped system with constant coefficients (Hamiltonian system). The denominator n represents the order of the parametric resonance. This frequency is called a principal parametric resonance for $k = l$, and a parametric combination resonance for $k \neq l$. The systems analysed so far showed that the first order resonances, $n = 1$, are most significant, see e.g. [5–7].

2. Parametric anti-resonance

Almost all investigations on the dynamics of a single or of coupled differential equations having time-periodic coefficients are focusing on the resonant behaviour of parametric excitation; see e.g. [5–9]. The main focus there was to investigate the destabilising effect of parametric excitation, i.e. the instability boundary curves in the domain of system parameters. The non-resonant cases were not considered since they do not compromise the operation of a machine or do not amplify the system vibration in sensor applications. The benefit of introducing a non-resonant parametric excitation in an unstable coupled system was first highlighted in the pioneering work by Tondl in [10]. He showed that an unstable self-excited system can be stabilised by introducing a time-harmonic stiffness coefficient, a parametric excitation, at a specific parametric combination resonance frequency. Since this occurs at the frequency of a parametric resonance, the mechanism was named parametric anti-resonance.

Tondl's work initiated theoretical studies of several self-excited two-mass systems with time-harmonic stiffness using numerical simulation in [11,12] and analytical studies in [13,14]. The concept was enhanced to systems with time-harmonic damping [15] or inertia coefficients [16]. Almost all these investigations considered the variation of a single system parameter. Comprehensive analytical and numerical investigations for time-harmonic variations of a single as well as multiple physical parameters – a simultaneous variation of stiffness, damping and inertia coefficients – were carried out in [12,17]. This is especially relevant for implementations because in general it is rather difficult to control a single physical property without changing other properties in a specific system.

For a long time it had been believed that parametric anti-resonance can occur only in combination with self-excitation, see [11] and the review article [19]. However, the stabilising mechanism of a parametric anti-resonance was identified as the coupling of eigenvalues (vibration modes) of the underlying system with constant coefficients, see [20]. This qualitative interpretation drastically enlarged the applicability of the concept of damping by parametric excitation, since a properly chosen parametric anti-resonance not only stabilises an already unstable system (stabilisation by parametric excitation) but is also capable of enhancing the already existing damping; independent of self-excitation being present or not. Furthermore, introducing a parametric anti-resonance in a system with multiple degrees of freedom offers the unique possibility of coupling only two of the many vibration modes of the original system and induces an energy transfer between these selected vibration modes while the remaining vibration modes stay decoupled, at least in first order approximation [17,20]. The main theoretical contributions with respect to parametric anti-resonances in this context can be found in [10–12,17]. Recent reviews on the parametric anti-resonance can be found in [17,18] from which some findings are summarised in the following.

3. Basic physical interpretation

The physical interpretation of a parametric anti-resonance as an induced modal interaction, which incorporates a modal energy

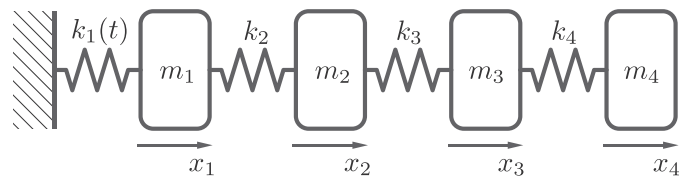


Fig. 1. Linear example system possessing four degrees of freedom x_i .

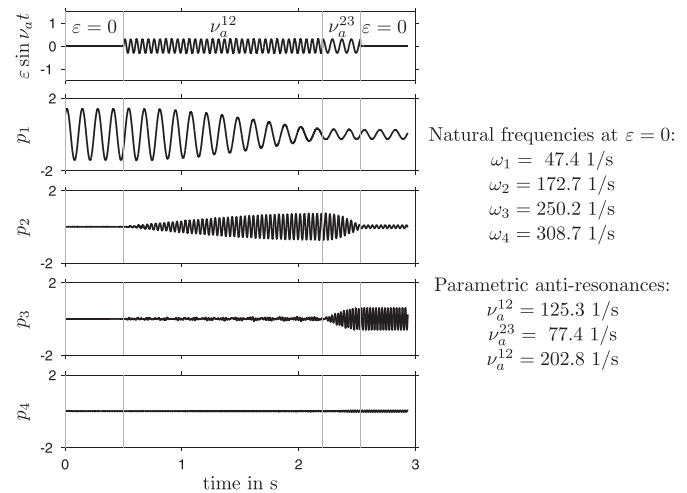


Fig. 2. Time series of modal displacements for the undamped system with cascaded time-periodicity (taken from [21]).

transfer, was proposed in [19] and the energy flow has been considered in [12,21]. This physical interpretation was rediscovered in [22]. In the following, the basic working principle of a parametric anti-resonance is outlined on a simple chain mass system with four degrees of freedom for which different parametric anti-resonances are realised by a harmonic stiffness variation, see Fig. 1. The physical interpretation proposed in [19] of coupling two of the many vibration modes of the underlying constant system is discussed in means of physical and modal time histories according to [17]. This interpretation leads intuitively to the calculation of the energy flow of each vibration mode and leads to clear physical insight of how parametric anti-resonances work.

Employing a properly tuned, time-periodic variation of at least one system parameter enables two things:

1. Inducing an energy transfer between only two of the many vibration modes of the underlying system with constant coefficients.
2. Increasing the energy dissipation due to improved action of the already existing damping element.

It has to be highlighted that vibration mitigation (energy dissipation) is only achieved due to the interaction of a parametric anti-resonance and the existing system damping. Both components are needed in order to realise a desired vibration mitigation.

It was shown in [17,20,21] that choosing specific parametric anti-resonance frequencies induces an energy transfer between different modes. This knowledge is exploited by introducing a cascaded time-periodic change of the stiffness element $k_1(t)$ in Fig. 1 as shown in Fig. 2 on the top. For the present study only $n = 1$ is considered which in general induces the strongest modal interaction. Starting with the undamped system with deactivated time-periodicity and initial conditions corresponding to the first mode, the stiffness coefficient is kept constant during the first 0.5 s. Then, the parametric anti-resonance frequency ν^{12} in (1) is

Download English Version:

<https://daneshyari.com/en/article/7126810>

Download Persian Version:

<https://daneshyari.com/article/7126810>

[Daneshyari.com](https://daneshyari.com)